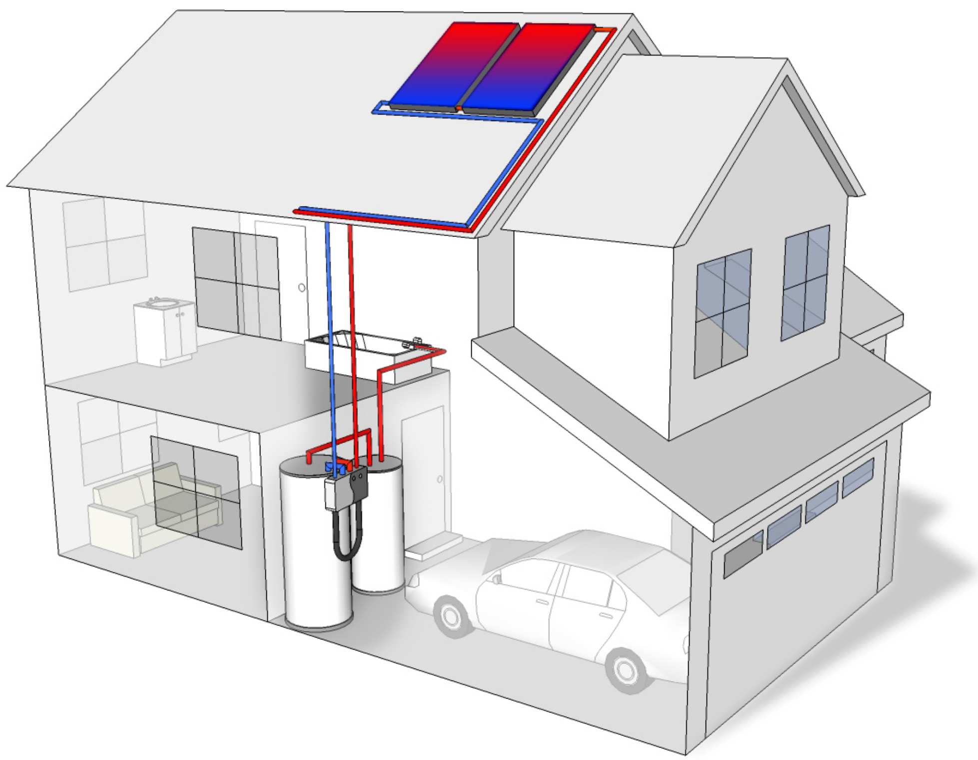
INTRODUCTION: SOLAR THERMAL TECHNOLOGY

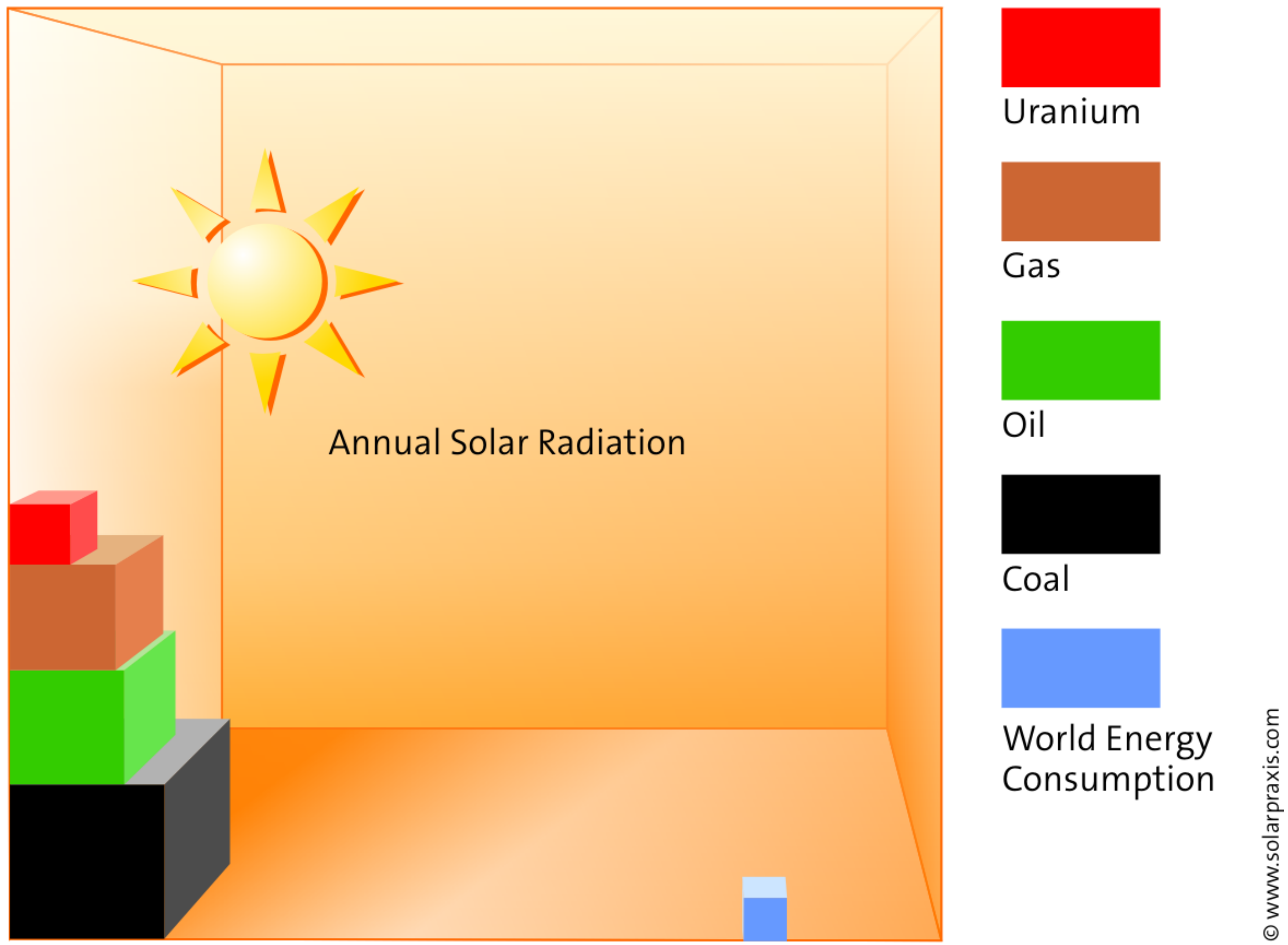
By: Ross Trethewey, MSME
TE2 Engineering, LLC.

What is Solar Thermal?

- Harness and convert solar energy into useful thermal energy.
- Applications
  - Domestic hot water
  - Space heating
  - Pool heating
  - Process heating
  - Car Washing
  - Cooling

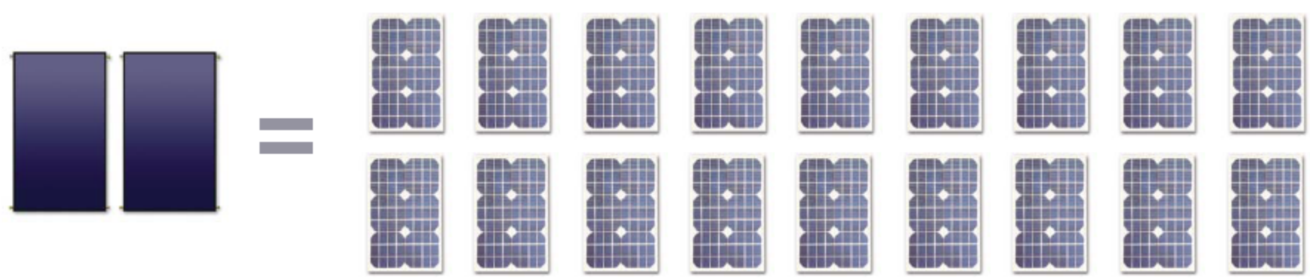


Why Solar - World Picture



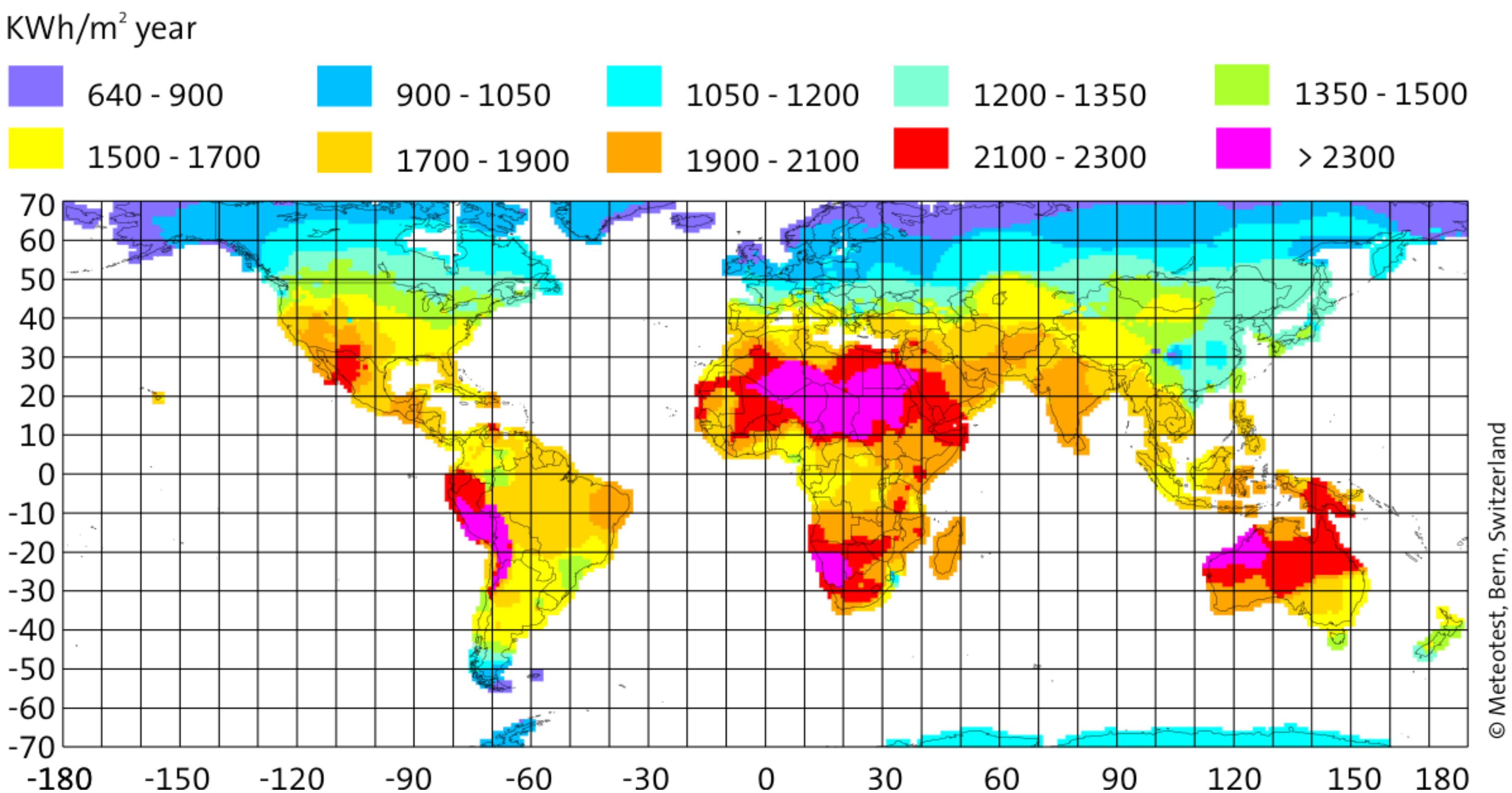
Why Solar Thermal?

- Energy independence
- Fluctuating energy prices
- Reduce carbon footprint
- Increase home/ building value
- Low upfront investment/ Fast ROI
- 3-6 Times More Efficient than Solar Photovoltaic (PV)



Output/day:	22.7 kWh	Output/day:	22.3 kWh (76,100 Btu)
Area:	80 ft^2	Area:	456 ft2 (18 panels)
Installed Cost:	$9,000	Installed Cost:	$30,000

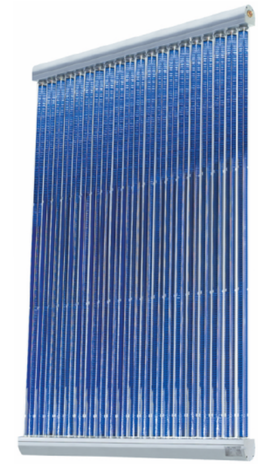
But We Don't Get Enough Sunlight…



Boston Insolation~ 500,000 Btu/ft^2 annually

Three Components

- **Collectors**
  - Flat Plate
  - Evacuated Tube
- **Pump Station/HX**
  - External HX
  - Pump-only
  - Controller included
- **Storage Tank**
  - Storage tank
  - Indirect tank
  - Dual Coil tank

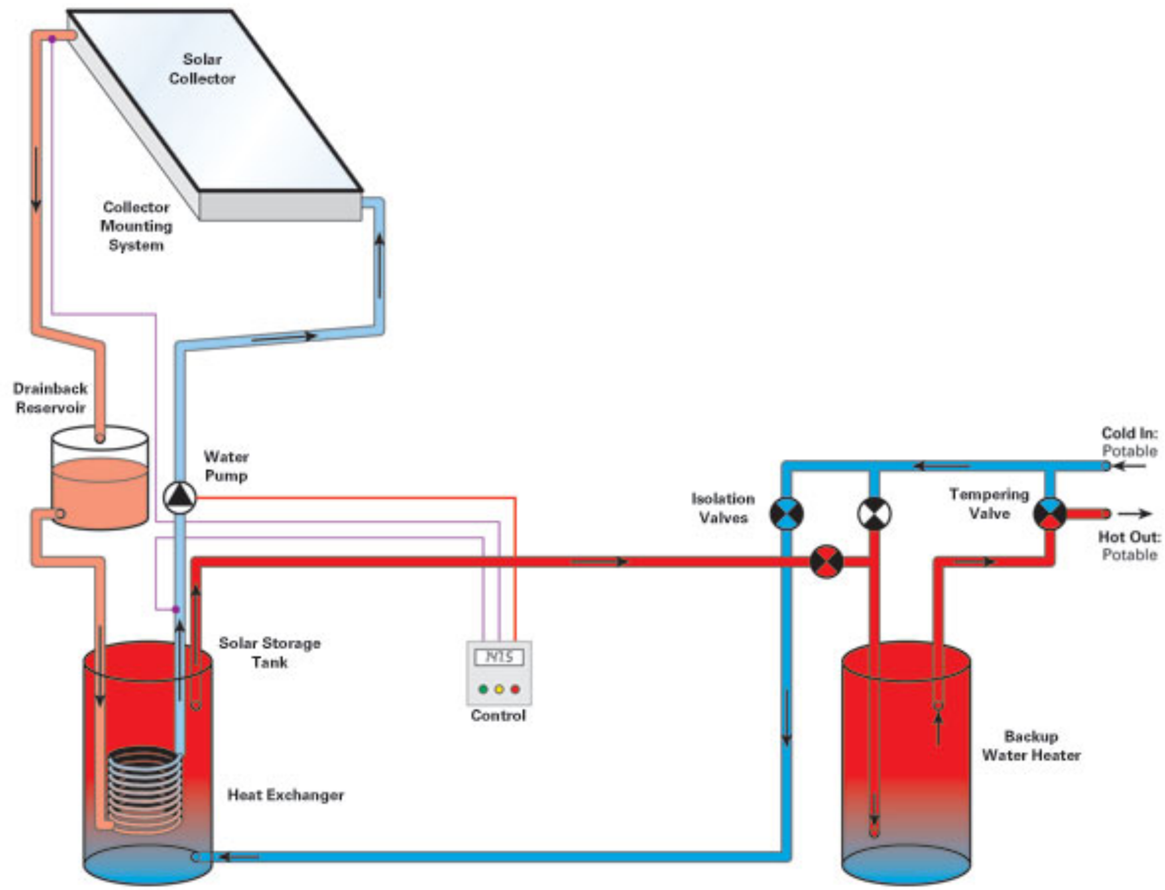







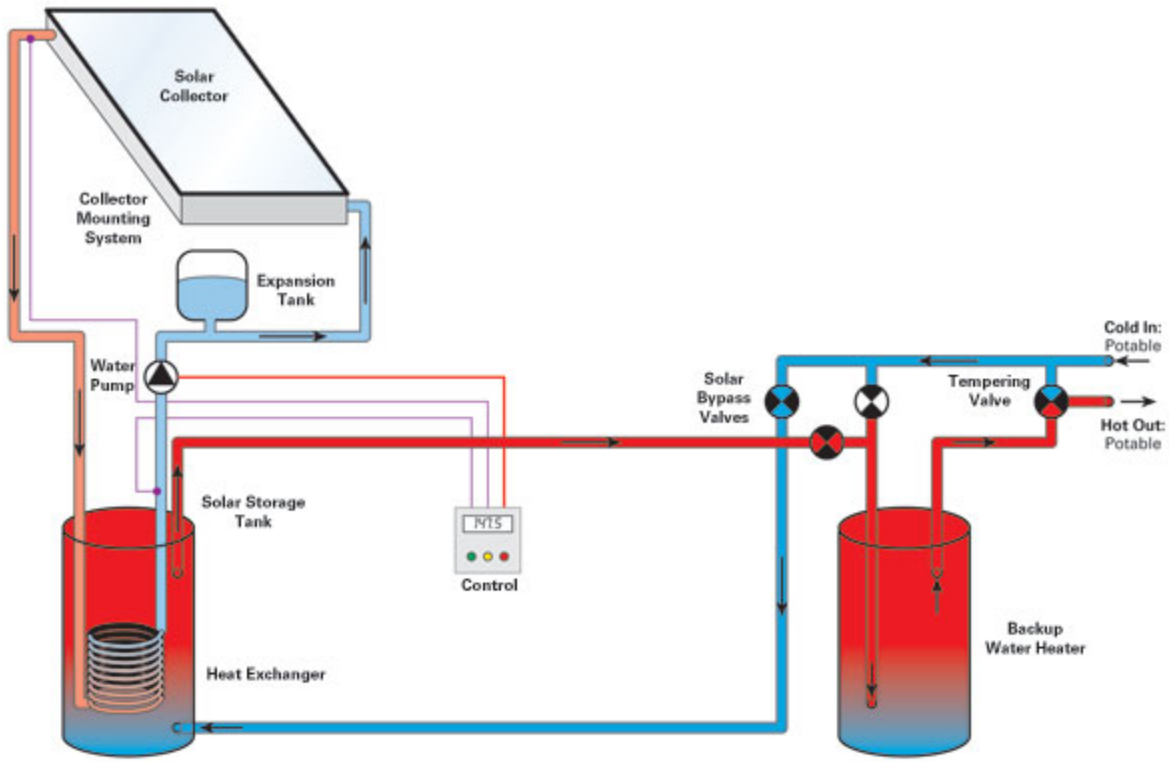
Drain Back Systems

- Advantages:
  - Can use Water
  - No Expansion Tank, Air Vent, Check Valve
  - Safe from power outages/ overheat
- Disadvantages
  - Careful installation- Everything must slope
  - High head pump(s)
  - Can be noisy
  - Mechanical/Electrical issue could be catastrophic

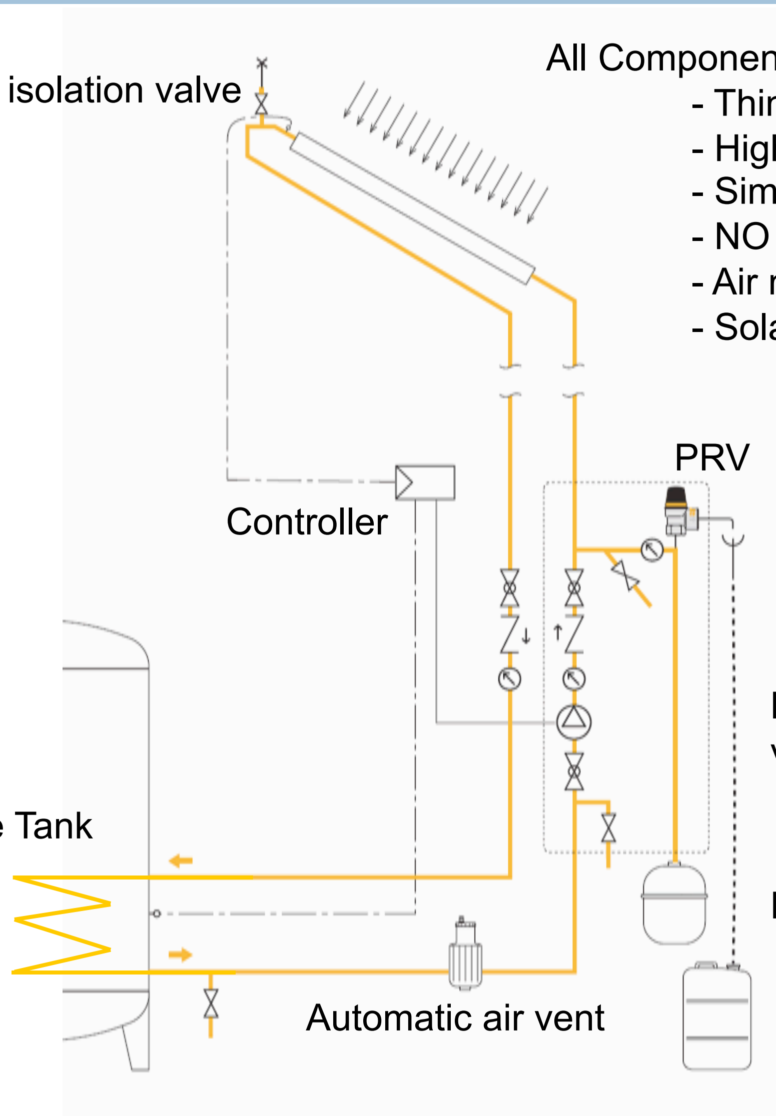


Pressurized Systems

- Advantages:
  - Freeze protected
  - Components do not need to be sloped
  - Low Wattage Pump
- Disadvantages:
  - Check glycol annually
  - Overheat during power outage or low load
    - Heat dissipation?



Piping Components

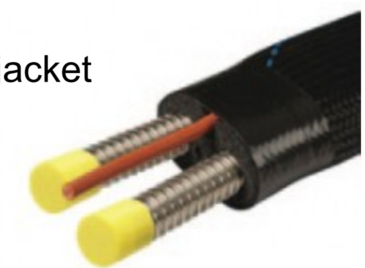


All Components must be rated for High Temperature and Pressure!

- Think of a solar system as a boiler that you can't turn off…
- High temp components, pipe connections and insulation
- Simple differential temperature control, with tank high limit
- NO plastic piping (i.e. PEX)
- Air must be removed effectively from system!
- Solar fluid must be recaptured

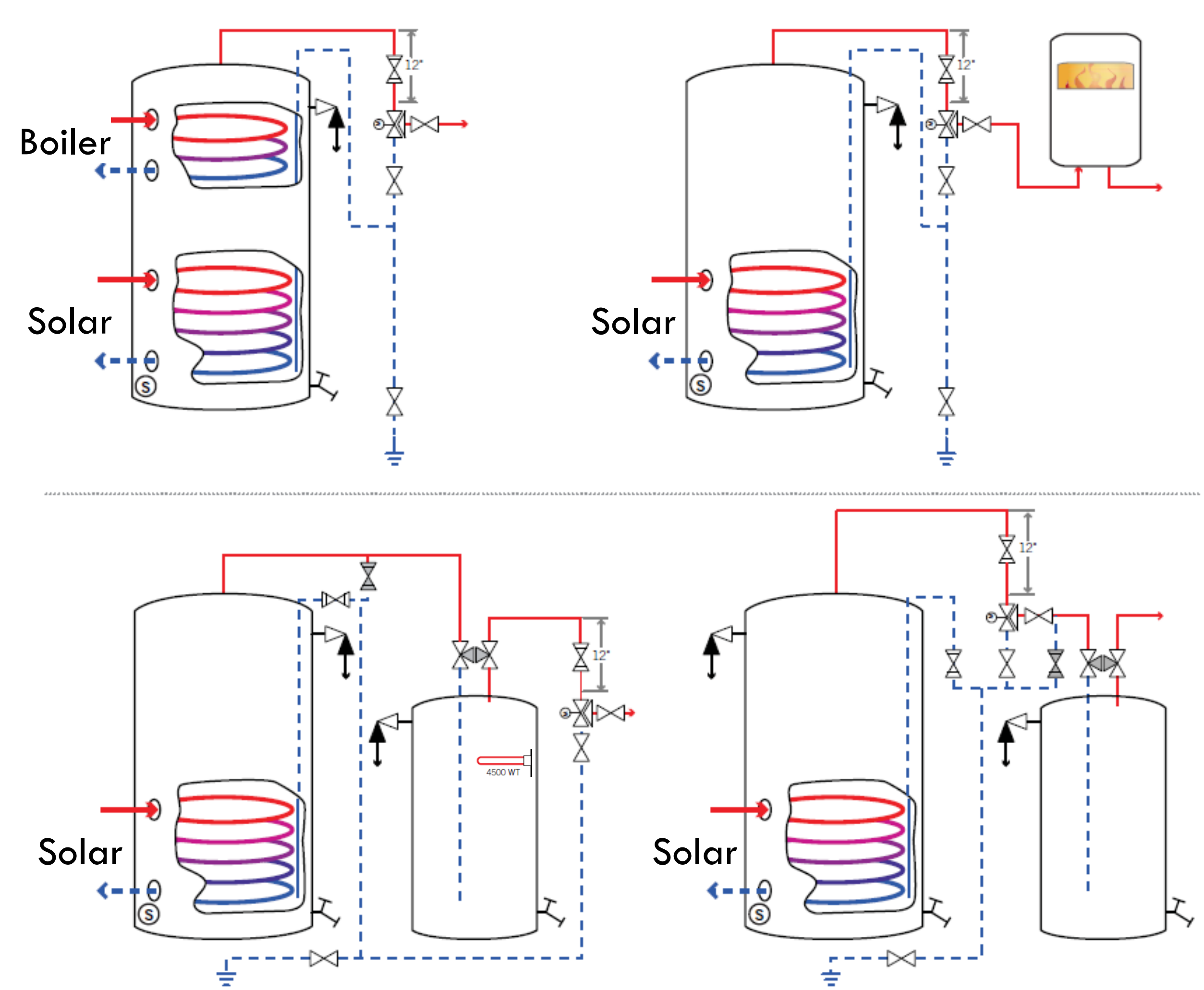
Pre-engineered stainless steel flexible linesets

- Insulation
- UV resistant jacket
- Sensor wire

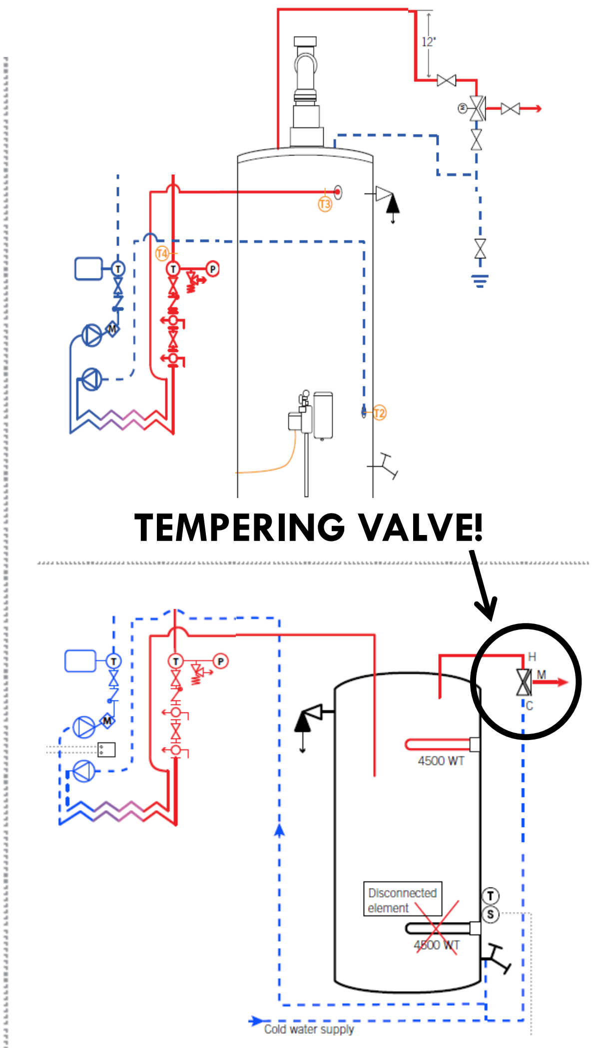


SHW Layout

INTERNAL HEAT EXCHANGER

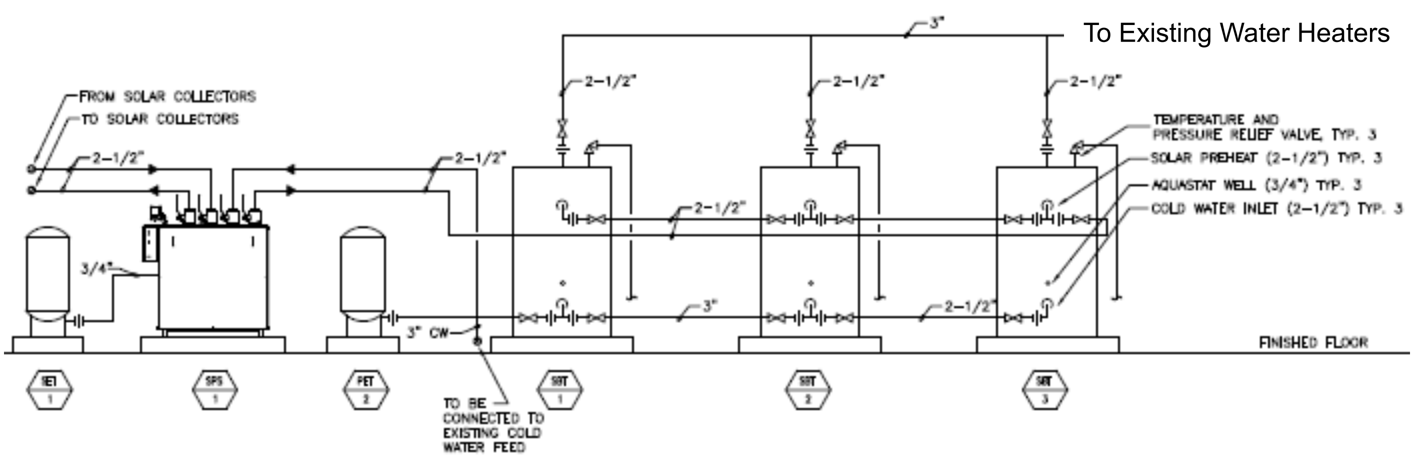


EXTERNAL HEAT EXCHANGER



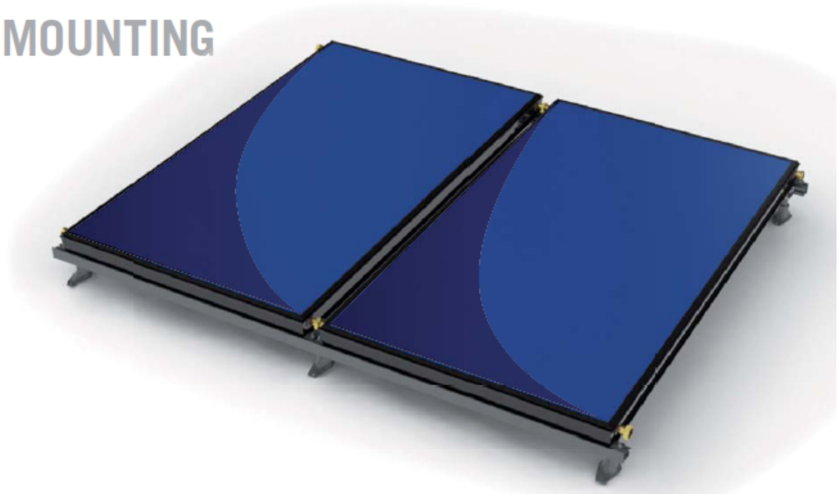
SHW Layout- Commercial

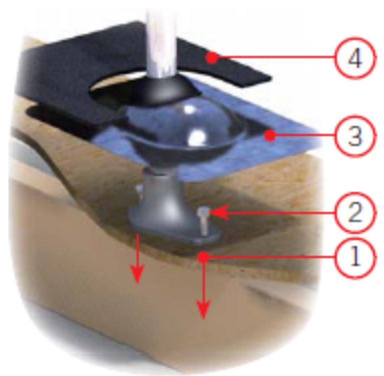
- External heat exchangers
  - Forced convection can provide up to 25% more heat exchange
  - Local codes may require Double-Wall HX
- Variable speed (ECM) pumps
  - Lower pump energy consumption
  - Reduce system short-cycling
- Plug and Play Appliances



Collector Racking

FLUSH MOUNTING





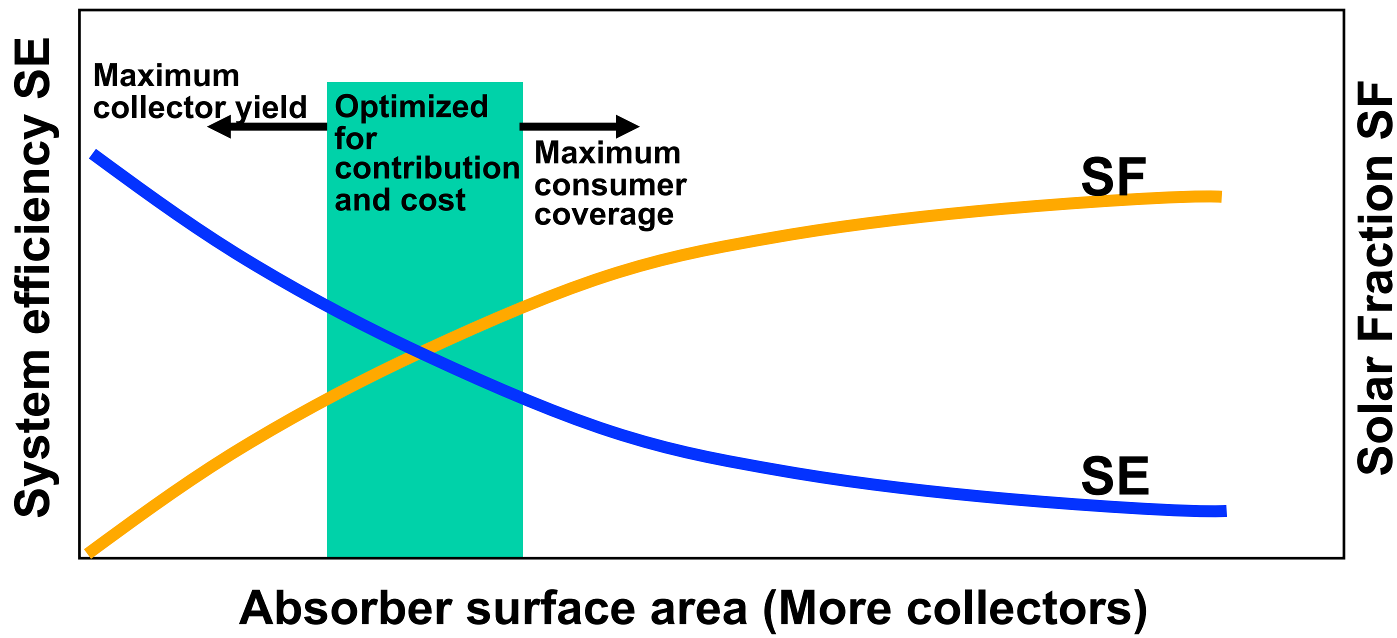
RACK MOUNTING

- Structural analysis to verify roof structure can withstand loads (weight, snow, uplift)
- Structural steel or ballasting may be required
- All Roof penetrations water-tight!

System Design for SHW

- Energy loads will dictate number of collectors…
  - Based on daily consumption (gal/day at certain temperature)
  - Also good to know the load profile (summer usage?)
- Match demand/collector array size to storage capacity…

Storage Capacity =1-1.5 gal/ft^2 of absorber area



Collector Performance

- SRCC OG-100 Rating
  - Collector Rating only
  - Snapshot view of collector performance (Plot Efficiency)
  - Collectors must have OG-100 to receive tax credits
- SRCC OG-300 Rating
  - Residential System Rating
- www.solar-rating.org

SOLAR COLLECTOR CERTIFICATION AND RATING

SRCC OG-100

CERTIFIED SOLAR COLLECTOR

SUPPLIER:	Heliodyne, Inc. 4910 Seaport Avenue Richmond, CA 94804 USA
MODEL:	GOBI 408 001
COLLECTOR TYPE:	Glazed Flat-Plate
CERTIFICATION#:	2010115D

COLLECTOR THERMAL PERFORMANCE RATING

Kilowatt-hours Per Panel Per Day				Thousands of BTU Per Panel Per Day			
CATEGORY (Ti-Ta)	CLEAR DAY	MILDLY CLOUDY	CLOUDY DAY	CATEGORY (Ti-Ta)	CLEAR DAY	MILDLY CLOUDY	CLOUDY DAY
A (-5 °C)	13.5	10.2	6.9	A (-9 °F)	46.2	34.9	23.7
B (5 °C)	12.3	9.0	5.7	B (9 °F)	42.0	30.8	19.5
C (20 °C)	10.5	7.3	4.1	C (36 °F)	35.8	24.8	13.8
D (50 °C)	7.2	4.2	1.3	D (90 °F)	24.5	14.2	4.6
E (80 °C)	4.3	1.6	0.0	E (144 °F)	14.6	5.6	0.0

A- Pool Heating (Warm Climate) B- Pool Heating (Cool Climate) C- Water Heating (Warm Climate) D- Water Heating (Cool Climate) E- Air Conditioning

Original Certification Date: 28-MAR-11

COLLECTOR SPECIFICATIONS

Gross Area:	2.993 m^2	32.22 ft^2
Dry Weight:	46.3 kg	102. lb
Test Pressure:	1103. KPa	160. psig

Net Aperture Area:	2.78 m^2	29.93 ft^2
Fluid Capacity:	2.6 liter	0.7 gal

COLLECTOR MATERIALS

Frame:	Aluminum
Cover (Outer):	Tempered glass
Cover (Inner):	

Pressure Drop

Flow		ΔP	
ml/s	gpm	Pa	in H_2O

Absorber Material:	Tube - Copper / Plate - Aluminum	Insulation Side:	Foam
Absorber Coating:	Selective coating	Insulation Back:	foam

TECHNICAL INFORMATION

Efficiency Equation [NOTE: Based on gross area and (P)=Ti-Ta]				Y INTERCEPT	SLOPE
SI Units:	η= 0.749	-3.69060 (P)/I	-0.00551 $(P)^2$/I	0.752	-4.029 $W/m^2 \cdot °C$
IP Units:	η= 0.749	-0.65010 (P)/I	-0.00054 $(P)^2$/I	0.752	-0.710 $Btu/hr.ft^2 \cdot °F$

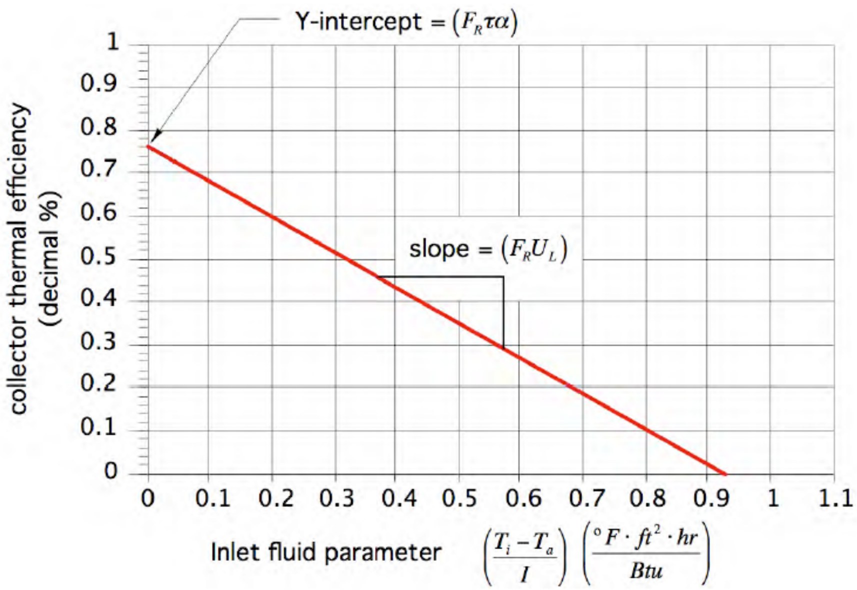
Incident Angle Modifier [(S)=1/cosθ - 1, 0°<θ<=60°]

Kτα = 1	-0.078 (S)	-0.086 $(S)^2$
Kτα = 1	-0.17 (S)	Linear Fit

Test Fluid:	Water	
Test Flow Rate:	27.7 ml /s.m^2	0.0408 gpm/ft^2

Collector Thermal Efficiency

- Optical losses
  - Typically 20% loss of solar transmission through glass
- Thermal losses
  - Function of ambient air temperature, inlet fluid temperature and solar radiation



$$\eta_{collector} = (F_R\tau\alpha) - (F_R U_L) \times \left[\frac{T_i - T_a}{I}\right]$$

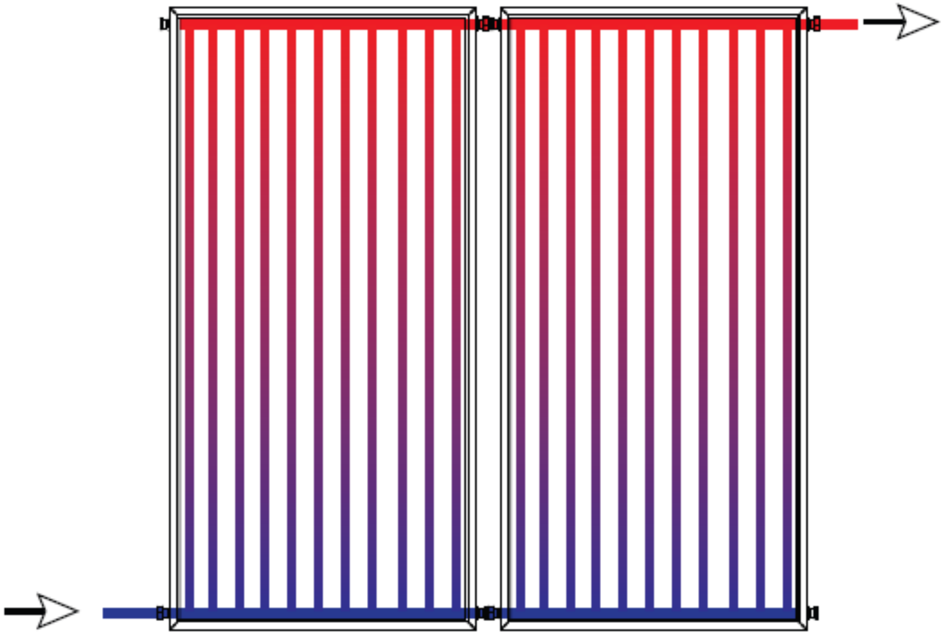
Where:
T_i = inlet fluid temperature to collector (°F)
T_a = ambient air temperature surrounding collector (°F)
I = solar radiation intensity incident on collector (Btu/hr/sq. ft.)
Frta = Y-intercept (determined through testing)
FrUL = slope of efficiency line (determined through testing)

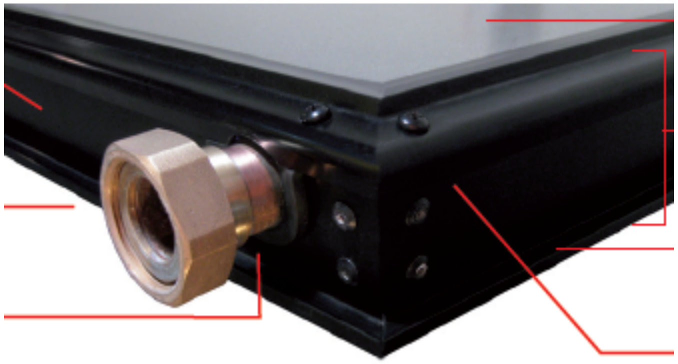
RST Thermal

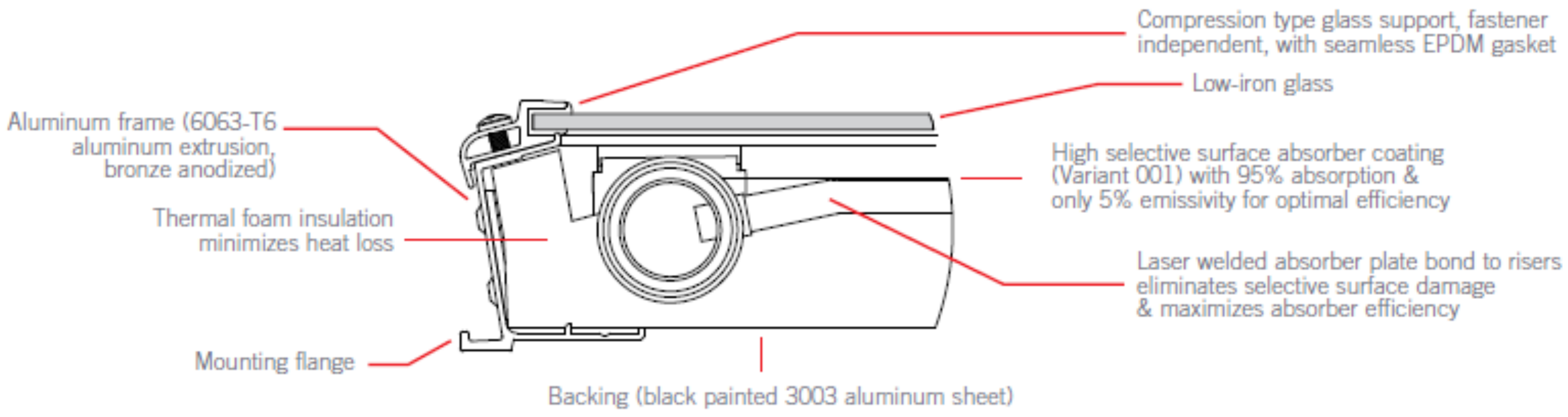
Unglazed Plastic Collectors

- Typically used for pool heating
- Advantages
  - Inexpensive
- Disadvantages
  - Low temperature rise
  - No insulation
  - No tax credits/rebates

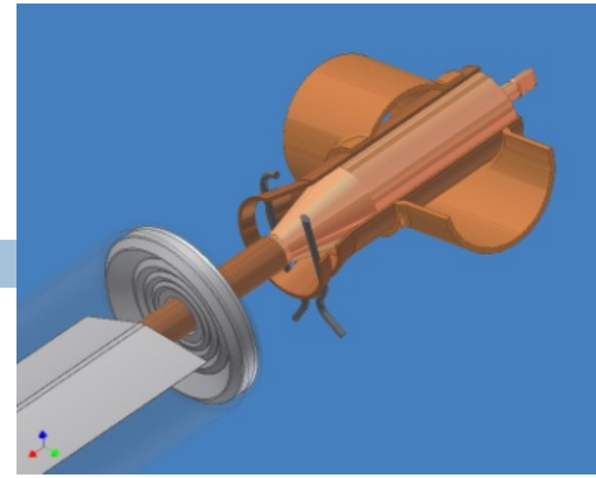
Glazed Flat Plate



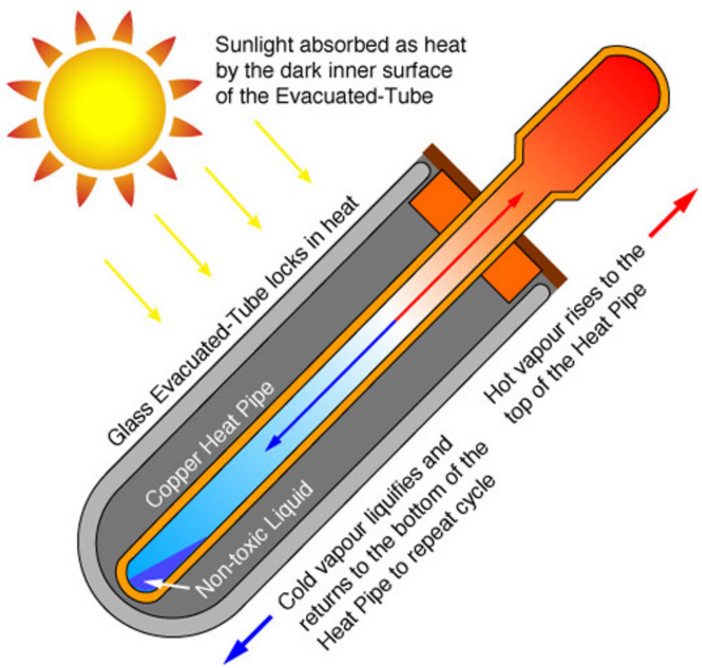


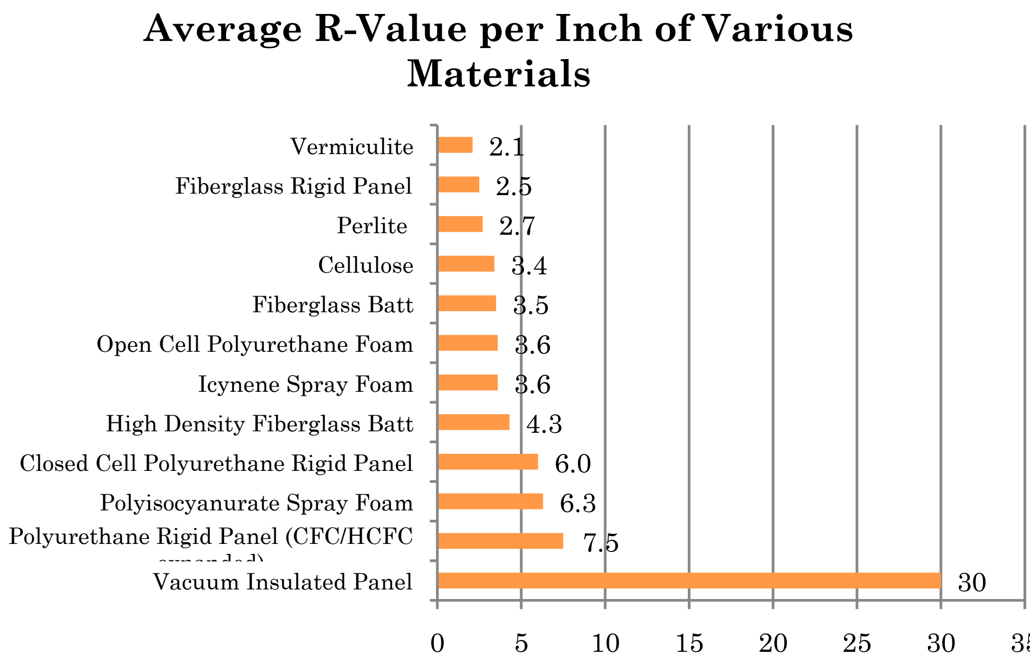


Evacuated Tube



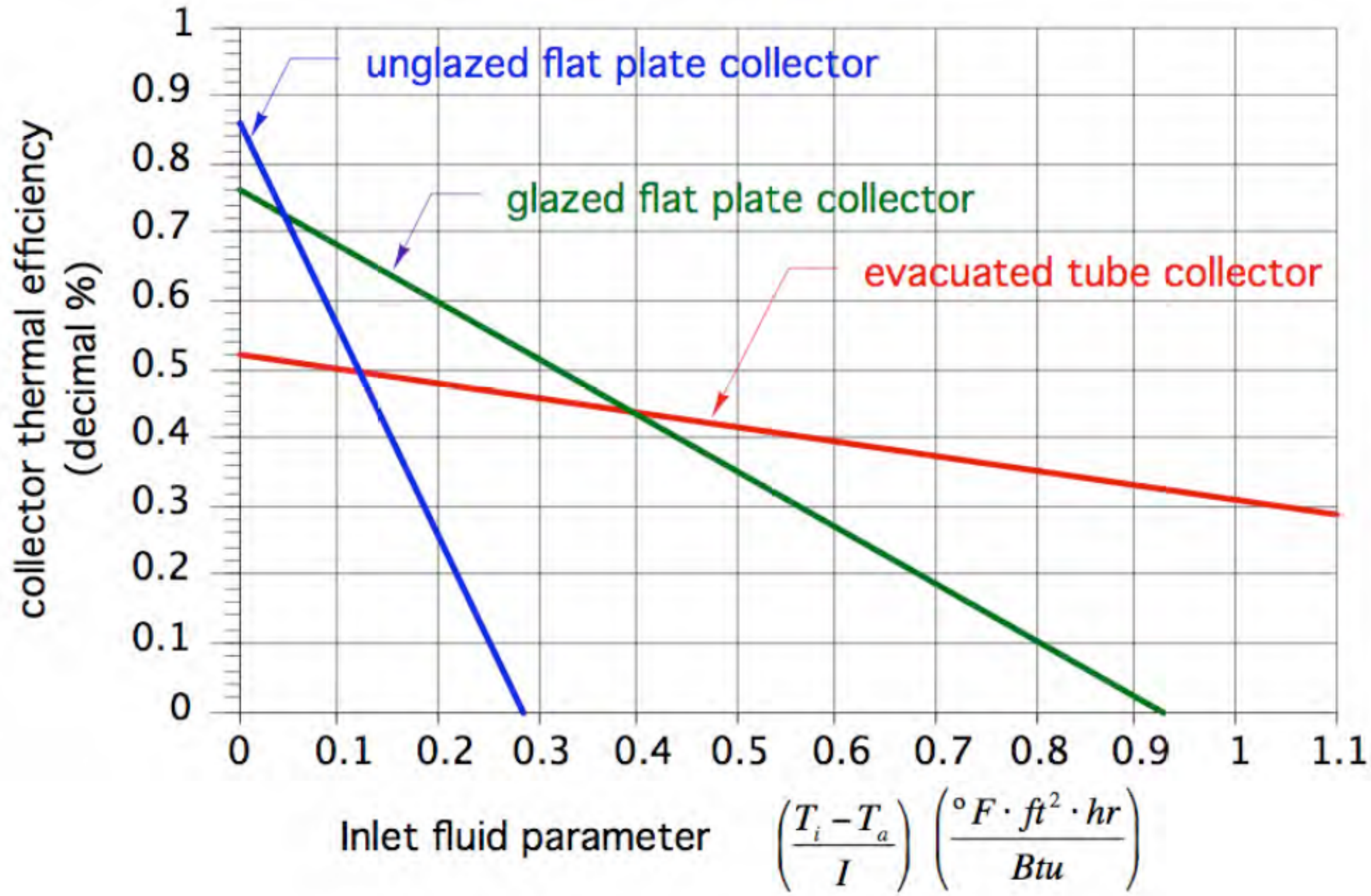
- Heat Pipe and Direct Flow





Minimum Inclination = 20°
Recommended Minimum = 35° (to shed snow)

Which is More Efficient?

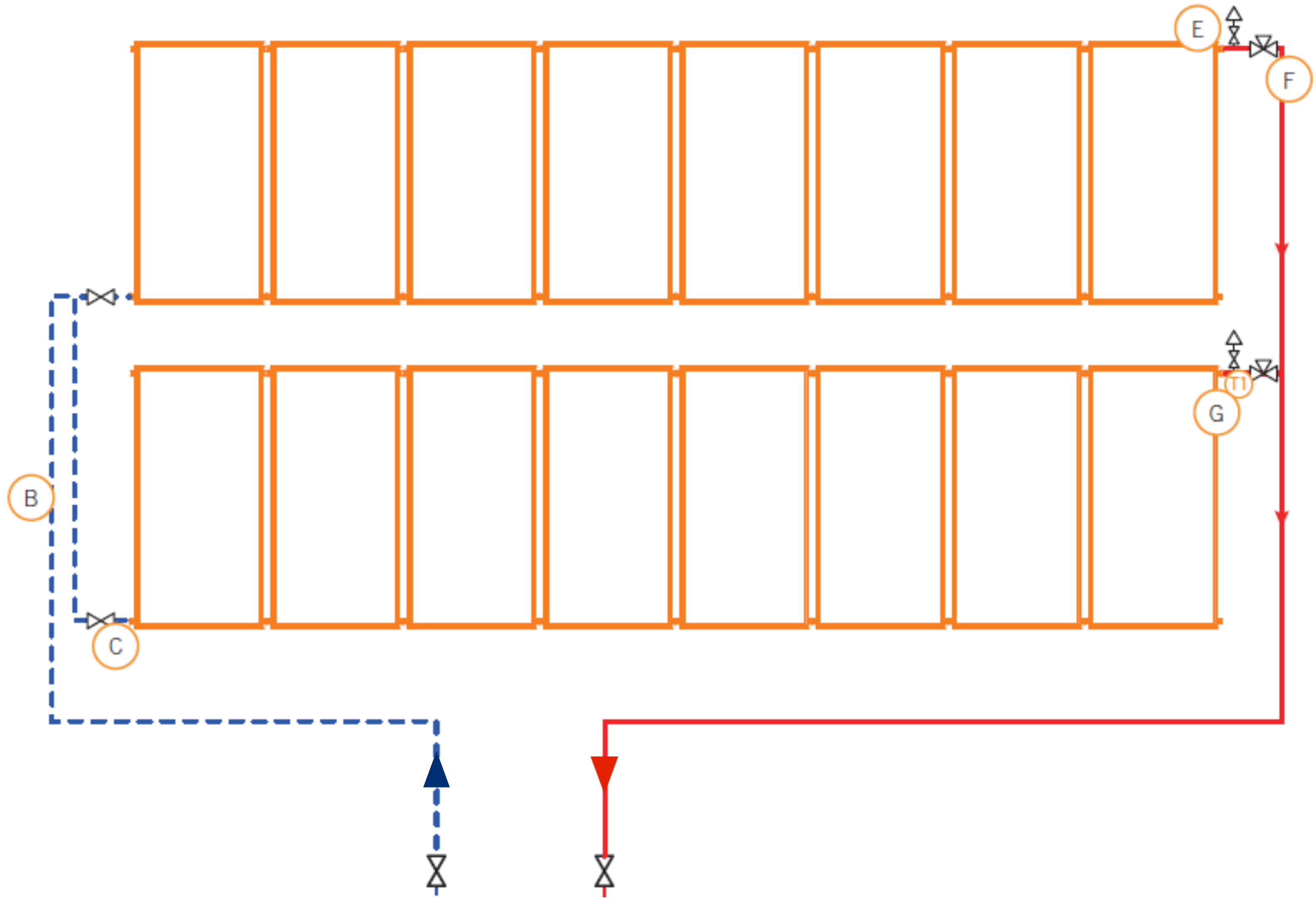


Where do the lines intersect?

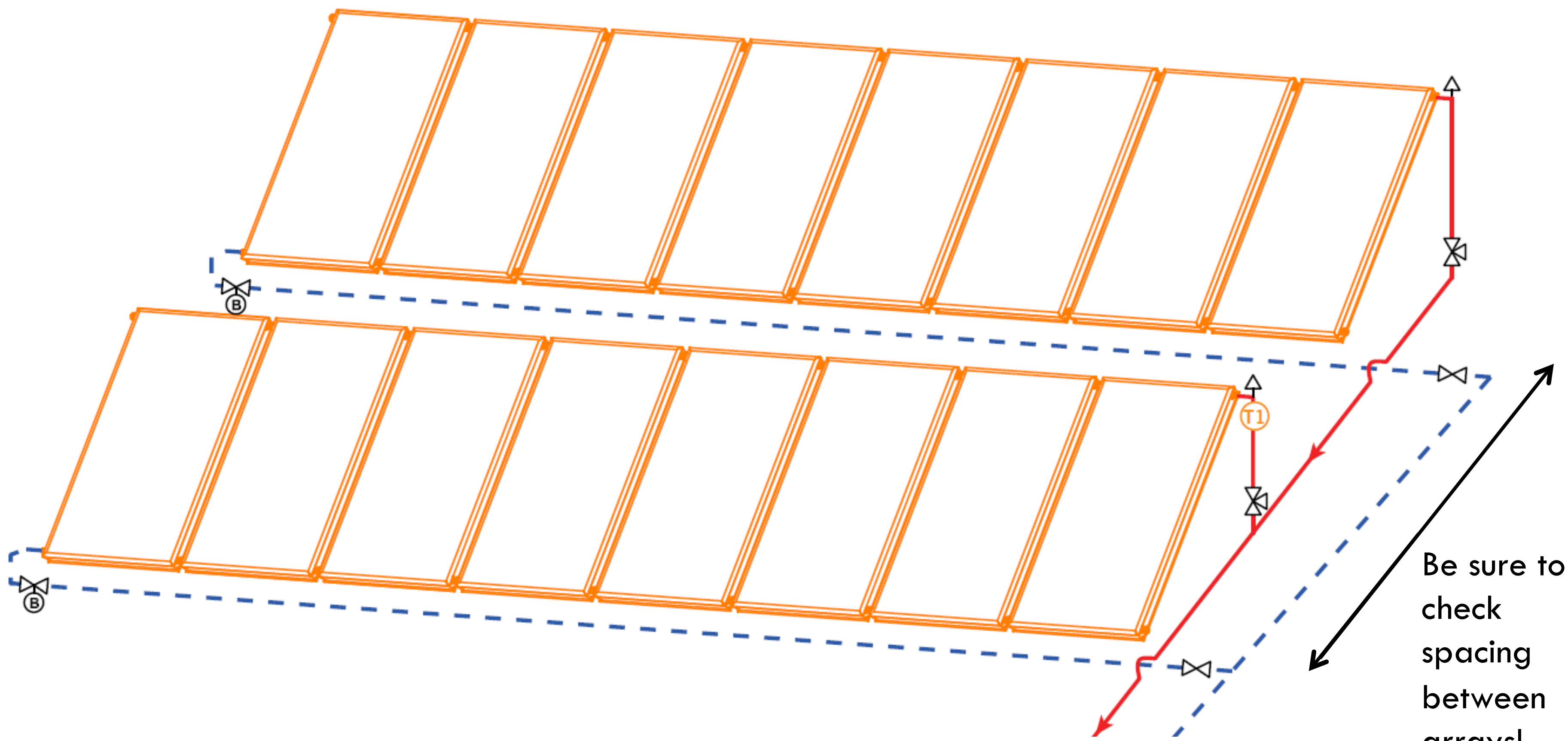
20°F Ambient, Reasonably Bright Day (250 Btuh/sq. ft), with 120°F fluid temp = Fluid Parameter 0.4

* Efficiency curves based on gross surface area of collectors. Durability, Service and Cost must also be evaluated.

Balanced Flow: Reverse-Return Piping



Balanced Flow: Balancing Valves



Be sure to check spacing between arrays!

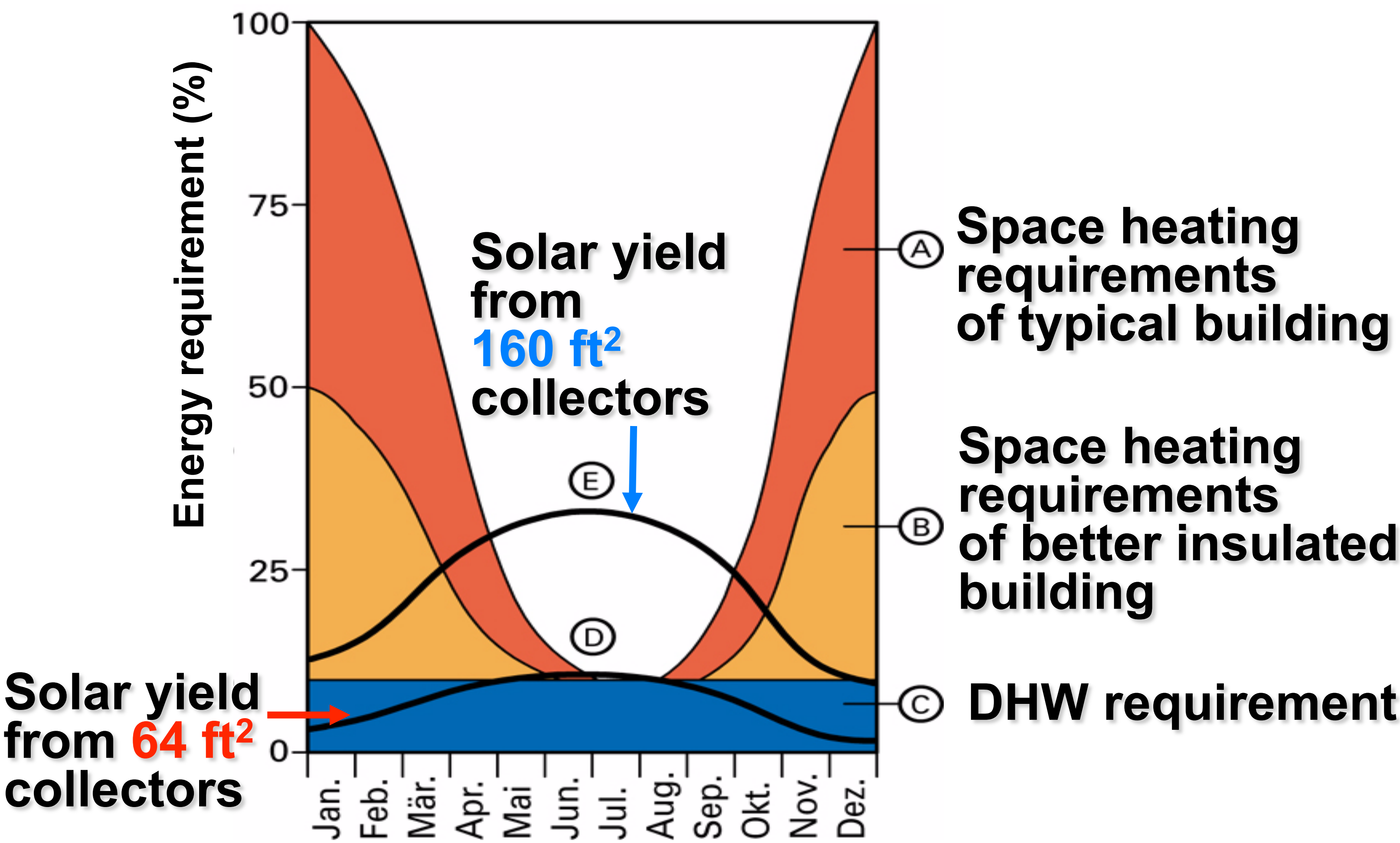
Realistic Expectations for Solar

- Most people have an unrealistic expectation of what solar can actually do…
- So we need to educate!
  - 2 collectors on a house will heat domestic hot water for a family of 4!
  - Larger arrays can provide space heat but typically 20-40% of the total space heating load maximum.

Space Heat/Pool Heat

- Space Heating
  - Based on heating load, heating emitter, design water temperature, usage, demand offset?
  - Matches up well with low water temperature designs (radiant floor heat, high surface area convectors, radiators, fan coils)
  - If you need 180°F water temps, solar is probably not the right fit!
- Pool Heating
  - Based on surface area, depth, indoor/outdoor, usage, design temperature, pool environment, pool cover?
  - Pool covers should be required!

Space Heating "Combi" Systems



Overheating (Stagnation)

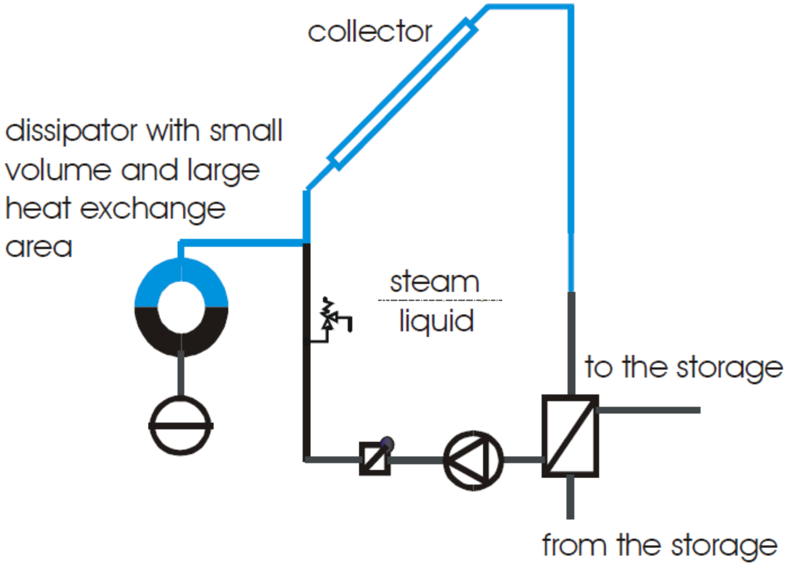
- Pressurized solar thermal systems will experience stagnation at some point.
  - Causes:
    - Oversized Collector Array
    - Tank Temperature Satisfied
    - Low Energy Consumption
    - Power Outage
      - unless PV-DC powered pumps or backup generator
    - Control/Sensor/Pump Failure
- How hot can it get?
  - Depends on conditions and collector type…
  - For flat plate: $\eta_{collector} = (F_R\tau\alpha) - (F_R U_L)\left[\frac{T_i - T_a}{I}\right] = 0$

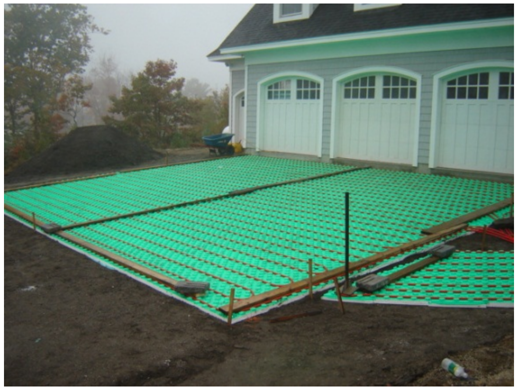
$$T_{stagnation} = \left[\frac{(F_R\tau\alpha)}{(F_R U_L)}\right] I + T_a$$

$$T_{stagnation} = \left[\frac{(F_R\tau\alpha)}{(F_R U_L)}\right] I + T_a = \left[\frac{0.706}{.865}\right] 317 + 85 = 344^\circ F$$

Ways to Limit Stagnation

- Higher Collector Inclination Angle
- Collector Cover
- Heat Dissipation (active and passive)
- "Vacation Mode" (only with flat plates)





Solar Glycol

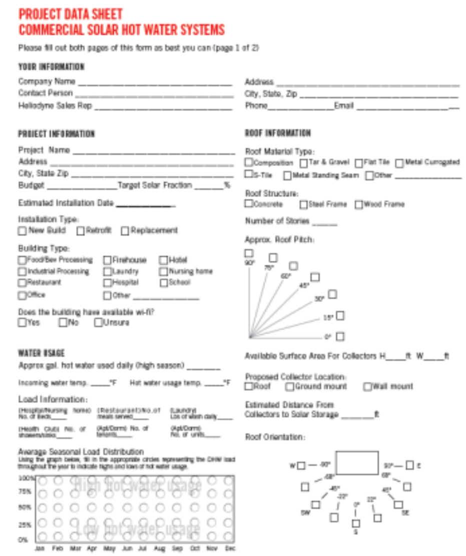
- Solar Glycol Characteristics
  - 50% Propylene Glycol
  - 50% De-Ionized H2O (by vol.)
  - High Temp Corrosion Inhibitors
  - Wide range of temp (-31- 338 F)
  - pH of 7.5 – 8.5 (typical)

- Annually check glycol with refractometer or pH strip.

- Always flush system before filling with glycol! Recommended to use glycol cleaner solution or water with tri-sodium phosphate.

Design/Sales Process

- Identify quality applications
- Site Visit
  - Solar access
  - Roof space/condition
  - Solar checklist
- Design the solar system
  - For residential - Use tables
  - For commercial - Solar Simulation Report
- Integrate solar with backup systems
- Financial Feasibility
- Install the system!



PROJECT DATA SHEET
COMMERCIAL SOLAR HOT WATER SYSTEMS

Please fill out both pages of this form as best you can (page 1 of 2)

YOUR INFORMATION

Company Name ____ Address ____
Contact Person ____ City, State, Zip ____
Heliodyne Sales Rep ____ Phone ____ Email ____

PROJECT INFORMATION

Project Name ____
Address ____
City, State Zip ____
Budget ____ Target Solar Fraction ____%

Estimated Installation Date ____

Installation Type:
☐ New Build ☐ Retrofit ☐ Replacement

Building Type:
☐ Food/Bev Processing ☐ Firehouse ☐ Hotel
☐ Industrial Processing ☐ Laundry ☐ Nursing home
☐ Restaurant ☐ Hospital ☐ School
☐ Office ☐ Other ____

Does the building have available wi-fi?
☐ Yes ☐ No ☐ Unsure

ROOF INFORMATION

Roof Material Type:
☐ Composition ☐ Tar & Gravel ☐ Flat Tile ☐ Metal Corrugated
☐ S-Tile ☐ Metal Standing Seam ☐ Other ____

Roof Structure:
☐ Concrete ☐ Steel Frame ☐ Wood Frame

Number of Stories ____

Approx. Roof Pitch:
☐ 90° ☐ 75° ☐ 60° ☐ 45° ☐ 30° ☐ 15° ☐ 0°

WATER USAGE

Approx gal. hot water used daily (high season) ____

Incoming water temp. ____°F Hot water usage temp. ____°F

Load Information:
(Hospital/Nursing home) No. of beds ____ (Restaurant) No. of meals served ____ (Laundry) Lbs of wash daily ____
(Health Club) No. of showers/sinks ____ (Apt/Dorm) No. of tenants ____ (Apt/Dorm) No. of units ____

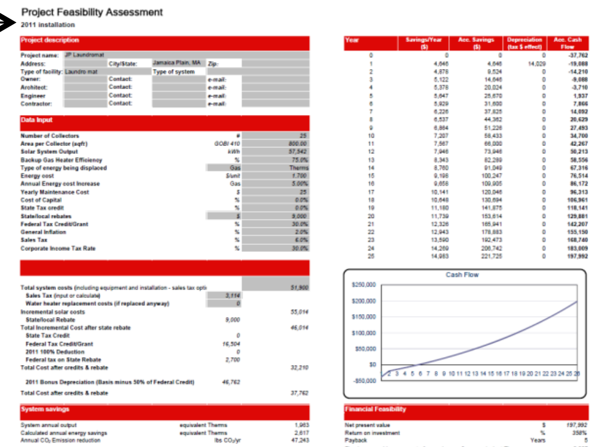
Average Seasonal Load Distribution
Using the graph below, fill in the appropriate circles representing the DHW load throughout the year to indicate highs and lows of hot water usage.

Available Surface Area For Collectors H____ft W____ft

Proposed Collector Location:
☐ Roof ☐ Ground mount ☐ Wall mount

Estimated Distance From Collectors to Solar Storage ____ft

Roof Orientation:



Project Feasibility Assessment
2011 installation

Project description					
Project name:	JP Laundromat				
Address:		City/State:	Jamaica Plain, MA	Zip:	
Type of facility:	Laundro mat		Type of system		
Owner:		Contact:		e-mail:	
Architect:		Contact:		e-mail:	
Engineer		Contact:		e-mail:	
Contractor:		Contact:		e-mail:	

Data Input		
Number of Collectors	#	25
Area per Collector (sqft)	GOBI 410	800.00
Solar System Output	kWh	57,542
Backup Gas Heater Efficiency	%	75.0%
Type of energy being displaced	Gas	Therms
Energy cost	$/unit	1.700
Annual Energy cost Increase	Gas	5.00%
Yearly Maintenance Cost	$	25
Cost of Capital	%	0.0%
State Tax credit	%	0.0%
State/local rebates	$	9,000
Federal Tax Credit/Grant	%	30.0%
General Inflation	%	2.0%
Sales Tax	%	6.0%
Corporate Income Tax Rate	%	30.0%

Total system costs (including equipment and installation - sales tax opti		51,900
Sales Tax (input or calculate)	3,114	
Water heater replacement costs (if replaced anyway)	0	
Incremental solar costs		55,014
State/local Rebate	9,000	
Total Incremental Cost after state rebate		46,014
State Tax Credit	0	
Federal Tax Credit/Grant	16,504	
2011 100% Deduction	0	
Federal tax on State Rebate	2,700	
Total Cost after credits & rebate		32,210
2011 Bonus Depreciation (Basis minus 50% of Federal Credit)	46,762	
Total Cost after credits & rebate		37,762

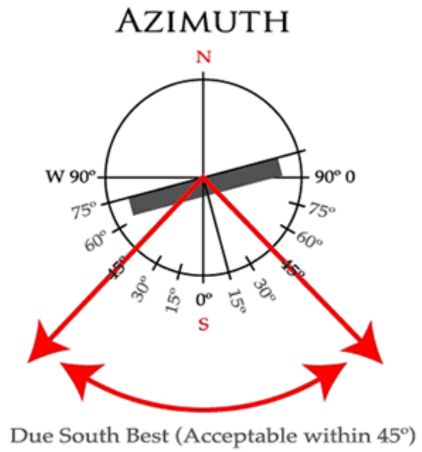
System savings		
System annual output	equivalent Therms	1,963
Calculated annual energy savings	equivalent Therms	2,617
Annual CO_2 Emission reduction	lbs CO_2/yr	47,243

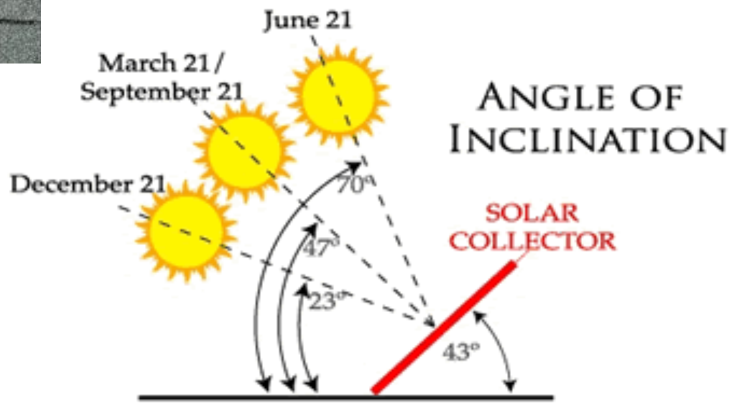
Year	Savings/Year ($)	Acc. Savings ($)	Depreciation (tax $ effect)	Acc. Cash Flow
0	0	0	0	-37,762
1	4,646	4,646	14,029	-19,088
2	4,878	9,524	0	-14,210
3	5,122	14,646	0	-9,088
4	5,378	20,024	0	-3,710
5	5,647	25,670	0	1,937
6	5,929	31,600	0	7,866
7	6,226	37,825	0	14,092
8	6,537	44,362	0	20,629
9	6,864	51,226	0	27,493
10	7,207	58,433	0	34,700
11	7,567	66,000	0	42,267
12	7,946	73,946	0	50,213
13	8,343	82,289	0	58,556
14	8,760	91,049	0	67,316
15	9,198	100,247	0	76,514
16	9,658	109,905	0	86,172
17	10,141	120,046	0	96,313
18	10,648	130,694	0	106,961
19	11,180	141,875	0	118,141
20	11,739	153,614	0	129,881
21	12,326	165,941	0	142,207
22	12,943	178,883	0	155,150
23	13,590	192,473	0	168,740
24	14,269	206,742	0	183,009
25	14,983	221,725	0	197,992

Financial Feasibility			
Net present value		$	197,992
Return on investment		%	358%
Payback		Years	5
Fixed comparable energy rate from solar	$ per equivalent Therms		0.007

Project Siting

- Roof, Wall or Ground Mount
  - Condition and type
  - Structure
- Azimuth angle
  - Solar South
  - Shading →
- Inclination angle
  - Annual ~ Latitude - 5°
  - Winter ~ Latitude + 15°





Financial Info

Data Input		
Number of Collectors	#	25
Area per Collector (sqft)	GOBI 410	800.00
Solar System Output	kWh	57,542
Backup Gas Heater Efficiency	%	75.0%
Type of energy being displaced	Gas	Therms
Energy cost	$/unit	1.700
Annual Energy cost Increase	Gas	5.00%
Yearly Maintenance Cost	$	25
Cost of Capital	%	0.0%
State Tax credit	%	0.0%
State/local rebates	$	9,000
Federal Tax Credit/Grant	%	30.0%
General Inflation	%	2.0%
Sales Tax	%	6.0%
Corporate Income Tax Rate	%	30.0%

Total system costs (including equipment and installation - sales tax opti		51,900
Sales Tax (input or calculate)	3,114	
Water heater replacement costs (if replaced anyway)	0	
Incremental solar costs		55,014
State/local Rebate	9,000	
Total Incremental Cost after state rebate		46,014
State Tax Credit	0	
Federal Tax Credit/Grant	16,504	
2011 100% Deduction	0	
Federal tax on State Rebate	2,700	
Total Cost after credits & rebate		32,210
2011 Bonus Depreciation (Basis minus 50% of Federal Credit)	46,762	
Total Cost after credits & rebate		37,762

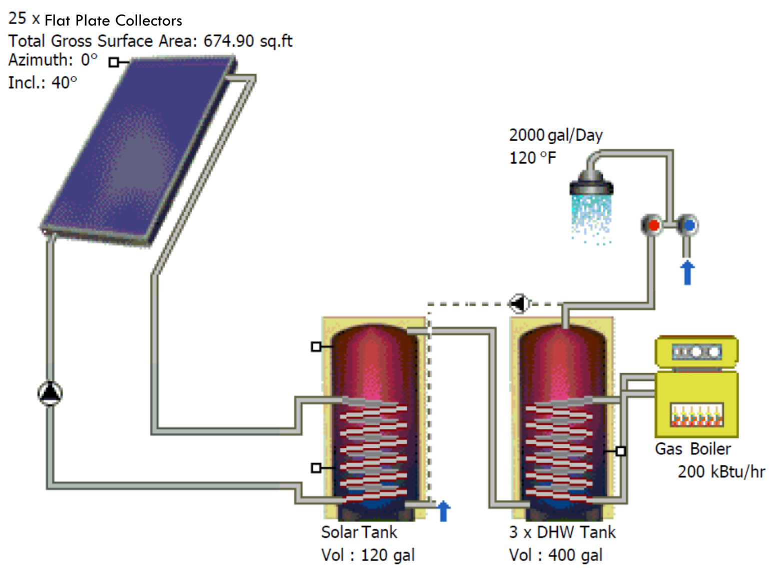
- Federal Tax Credit
  - 30% of installed cost (no cap)
- State Tax Credit (MA)
  - Residential-15% ($1,000)
- State Rebate (MA-CEC)
  - Residential Rebate- $25*SRCC Category C rating (cap $3,500)
  - Commercial Rebate- Based on Energy Offset (cap $10,000)
- Utility Rebates
  - Other incentives are available….just go to www.DSIREUSA.org

*Pool Heating solar systems do not qualify for tax credits!

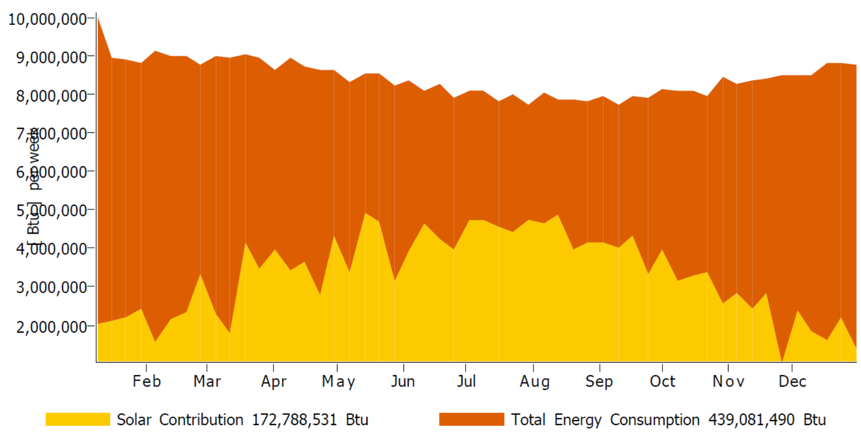
Case Study- Laundromat

- Laundromat
  - 2000 gal/day
  - Existing 3x 400 gallon tanks
  - Auxiliary Gas-Fired Water Heater
- Solar
  - 25 Flat Plate Collectors
    - 800 Square Feet
  - Solar Indirect Tank
  - Solar Pump Station

Laundromat- Solar Simulation



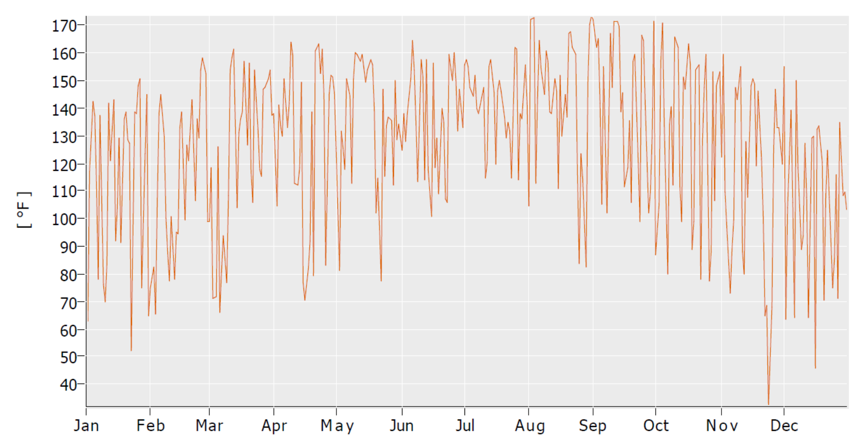
Solar Energy Consumption as Percentage of Total Consumption



Results of Annual Simulation

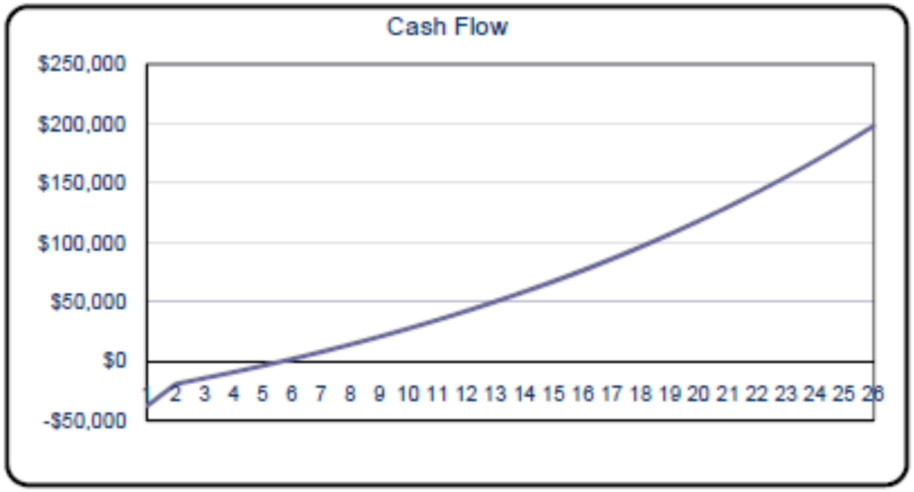
Installed Collector Power:	149.75 kBtu/hr	
Installed Gross Solar Surface Area:	674.9 sq.ft	
Collector Surface Area Irradiation (Active Surface):	321.47 MMBTU	513.39 kBtu/sq.ft
Energy Produced by Collectors:	173.04 MMBTU	276.34 kBtu/sq.ft
Energy Produced by Collector Loop:	171.98 MMBTU	274.66 kBtu/sq.ft
DHW Heating Energy Supply:	423.85 MMBTU	
Solar Contribution to DHW:	172.15 MMBTU	
Energy from Auxiliary Heating:	265.31 MMBTU	
Natural Gas (H) Savings:		**7,813.9 m³**
Natural Gas (H) Savings:		**2,788.37 therm**
CO2 Emissions Avoided:		**36,428.34 lbs**
DHW Solar Fraction:		**39.4 %**
Fractional Energy Saving (EN 12976):		**39.0 %**
System Efficiency:		**53.6 %**

Daily Maximum Collector Temperature



Laundromat- Financial Feasibility

Year	Savings/Year ($)	Acc. Savings ($)	Depreciation (tax $ effect)	Acc. Cash Flow
0	0	0	0	-37,762
1	4,646	4,646	14,029	-19,088
2	4,878	9,524	0	-14,210
3	5,122	14,646	0	-9,088
4	5,378	20,024	0	-3,710
5	5,647	25,670	0	1,937
6	5,929	31,600	0	7,866
7	6,226	37,825	0	14,092
8	6,537	44,362	0	20,629
9	6,864	51,226	0	27,493
10	7,207	58,433	0	34,700
11	7,567	66,000	0	42,267
12	7,946	73,946	0	50,213
13	8,343	82,289	0	58,556
14	8,760	91,049	0	67,316
15	9,198	100,247	0	76,514
16	9,658	109,905	0	86,172
17	10,141	120,046	0	96,313
18	10,648	130,694	0	106,961
19	11,180	141,875	0	118,141
20	11,739	153,614	0	129,881
21	12,326	165,941	0	142,207
22	12,943	178,883	0	155,150
23	13,590	192,473	0	168,740
24	14,269	206,742	0	183,009
25	14,983	221,725	0	197,992



Financial Feasibility

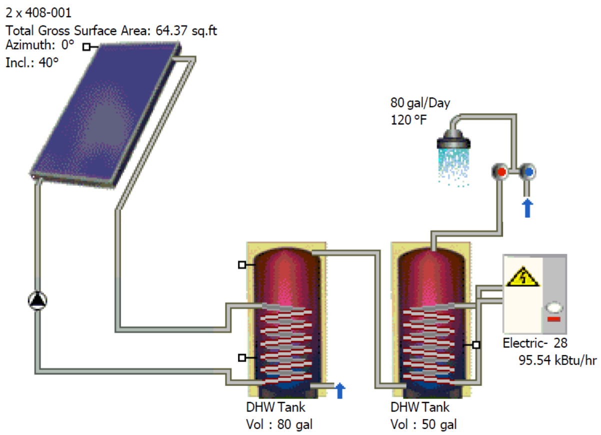
Net Present Value (NPV) = $197, 992

Simple Payback = 5 years

Annualized ROI = 19.5%

$$\text{Solar Thermal Rate} = \frac{\$37{,}762}{2788 \text{ therm/yr} * 25 \text{ yr}} = \$0.54 \text{ per therm}$$

Case Study- Residential



Annual Savings with "Standard Equipment"

Electric: 4250 kWh (@ $0.16/kWh) = **$680.00**

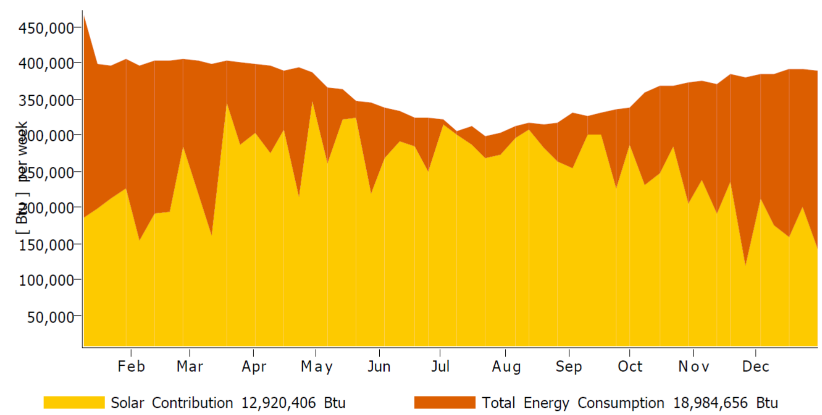
Oil: 170 gal (@ $3.90/gal) = **$663.00**

Natural Gas: 190 therms (@ $1.80/therm) = **$345.00**

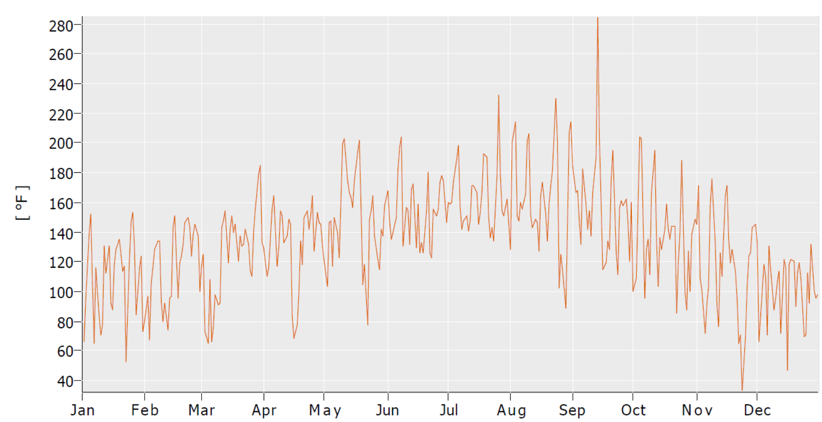
Results of Annual Simulation

Installed Collector Power:	14.28 kBtu/hr	
Installed Gross Solar Surface Area:	64.37 sq.ft	
Collector Surface Area Irradiation (Active Surface):	30.72 MMBTU	513.39 kBtu/sq.ft
Energy Produced by Collectors:	15.00 MMBTU	250.65 kBtu/sq.ft
Energy Produced by Collector Loop:	14.03 MMBTU	234.49 kBtu/sq.ft
DHW Heating Energy Supply:	17 MMBTU	
Solar Contribution to DHW:	12.87 MMBTU	
Energy from Auxiliary Heating:	6.04 MMBTU	
Electricity Savings:		**4,256.2 kWh**
CO2 Emissions Avoided:		**6,249.29 lbs**
DHW Solar Fraction:		**68.1 %**
Fractional Energy Saving (EN 12976):		**68.5 %**
System Efficiency:		**41.9 %**

Solar Energy Consumption as Percentage of Total Consumption



Daily Maximum Collector Temperature



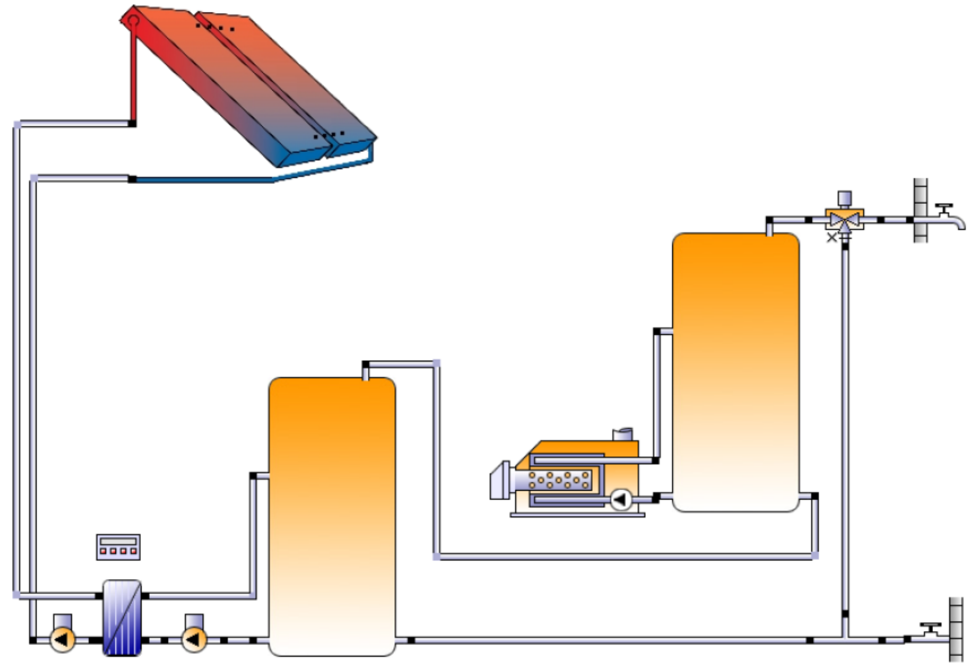
Residential System - Feasibility

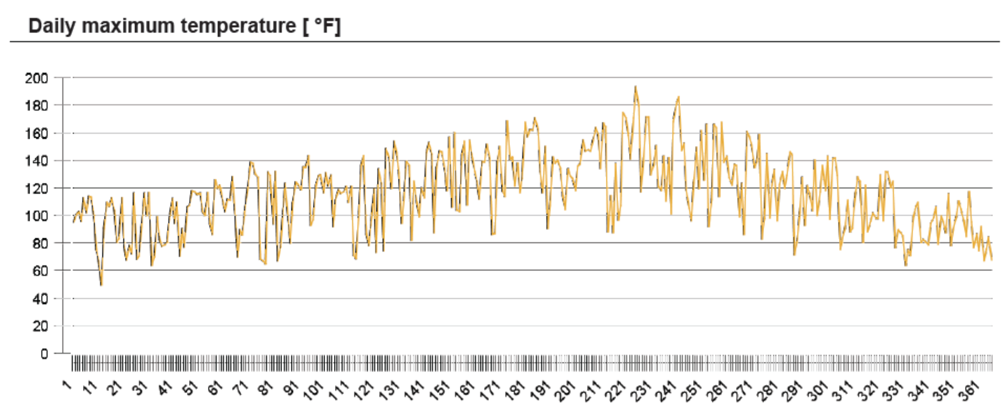
- System Initial Cost = $9,000
- Deductions:
  - Federal Tax Credit (30%)= $2,700
  - State Tax Credit (15%)= $1,000
  - State CEC Rebate= $1,300
  - Utility Rebates= $0
- System Real Cost= $4000

- For electric, oil or propane: ~ 5 year payback
- For natural gas (high efficiency): ~ 10 year payback

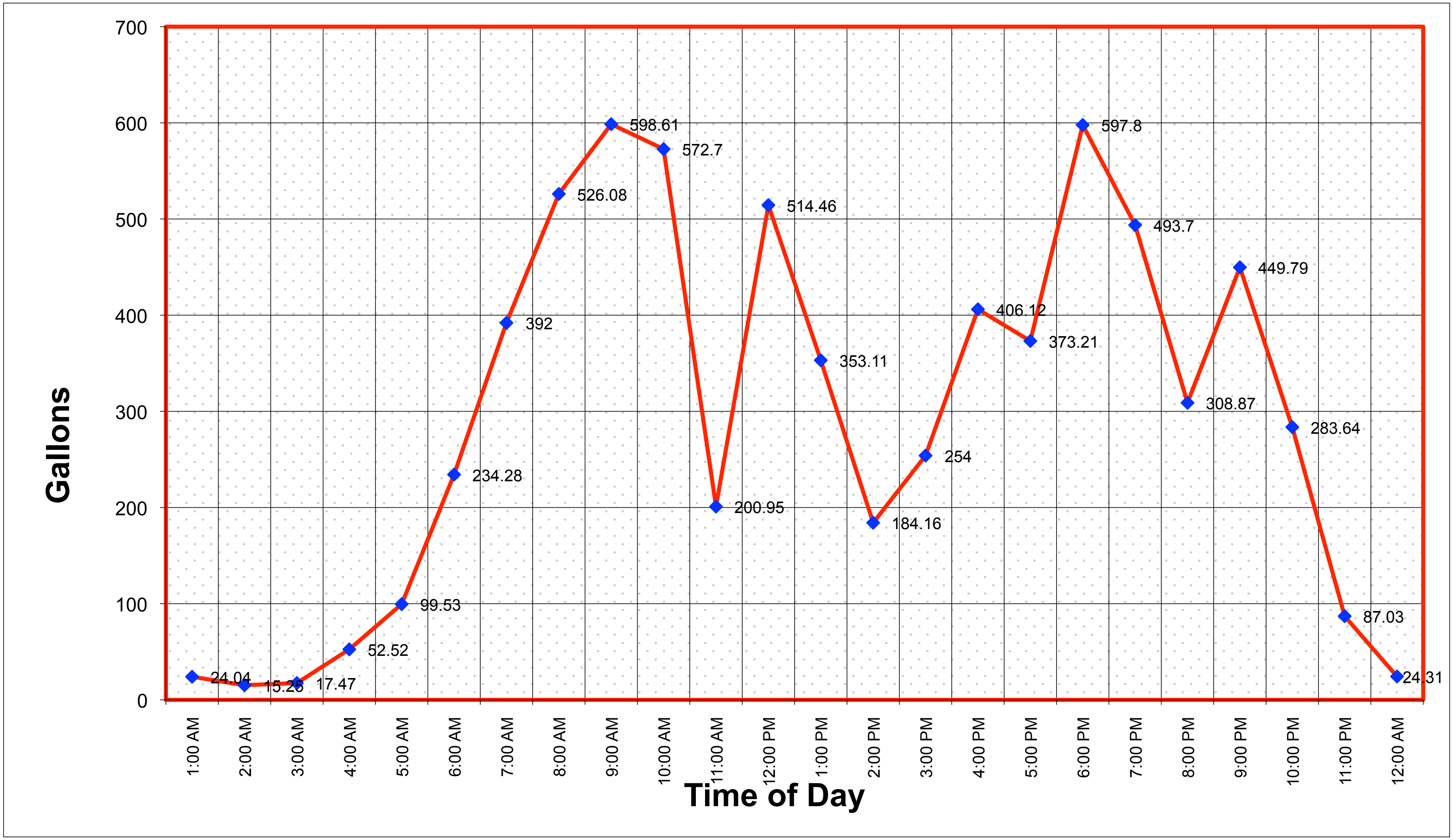
Case Study- NH Correctional Facility

- Closed Loop Pressurized
- Ground mount
- DHW Load: 6600 gal/day
  - Kitchen, Laundry, Showers
- 64 Collectors (2560 sq. ft)
  - 45 deg inclination
  - 0 deg azimuth
- 2250 gallons of solar storage
  - 3x 750 gallon tanks
- ~50% SF

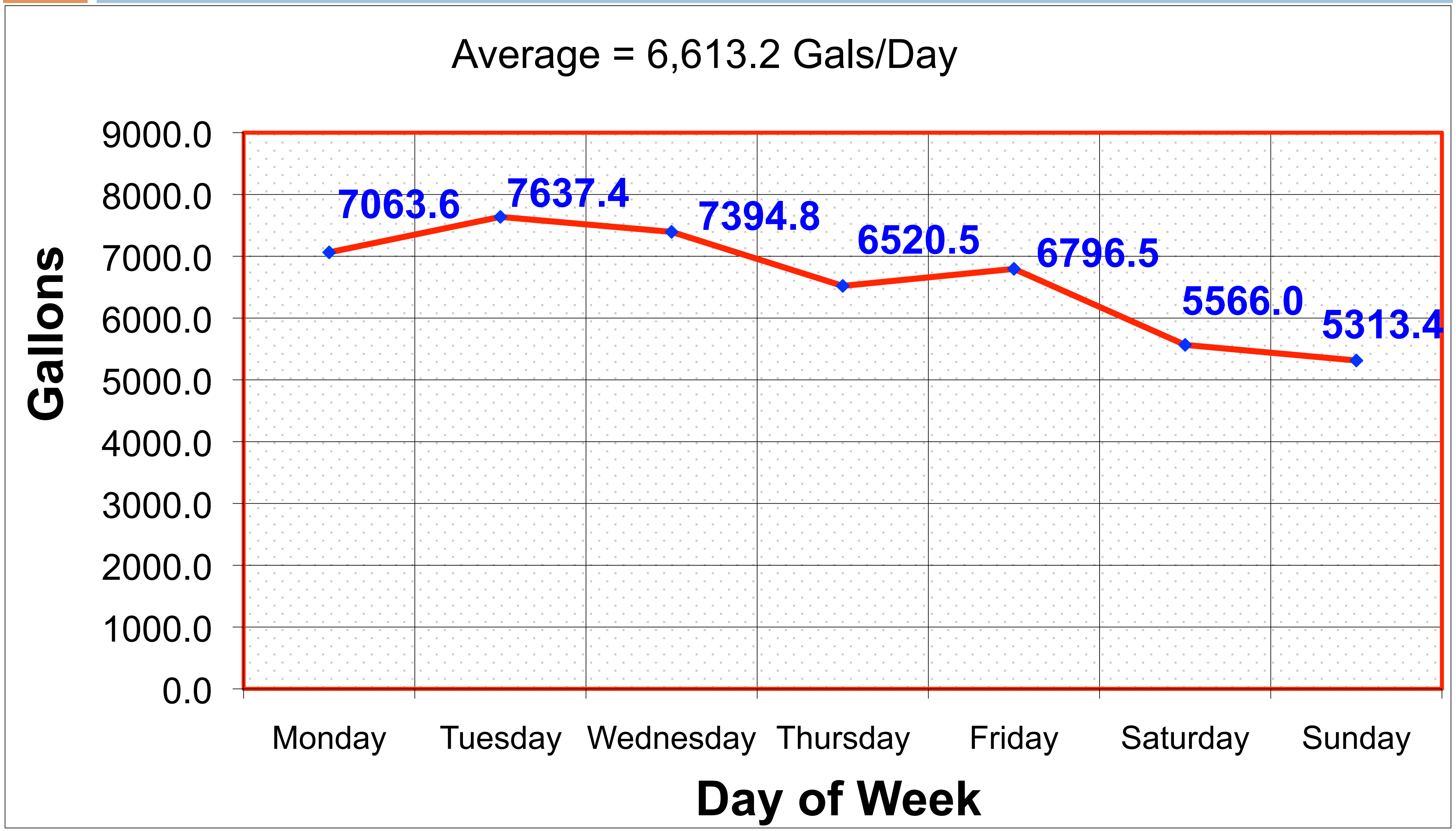




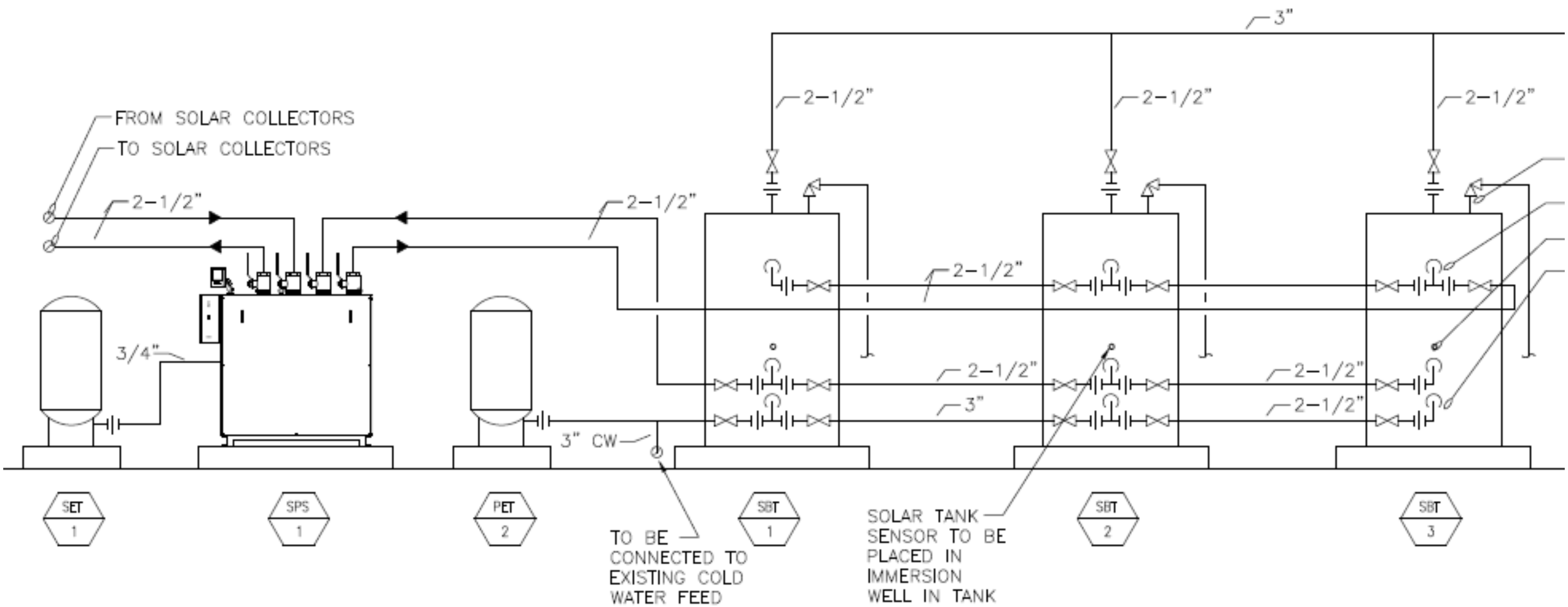
Load Profile- Typical Weekday



Weekly Use Summary



Solar System Conceptual Layout

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COLD WATER


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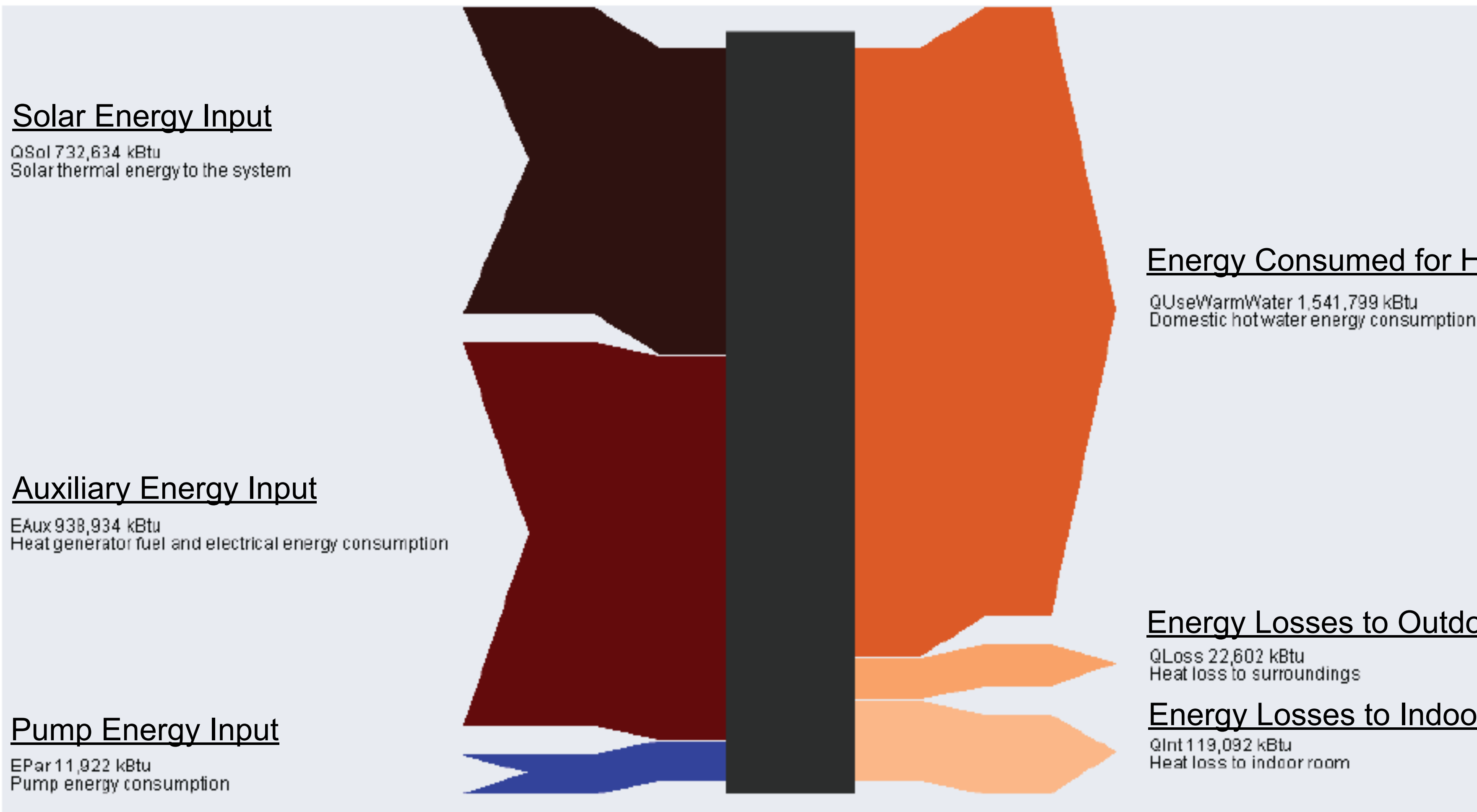
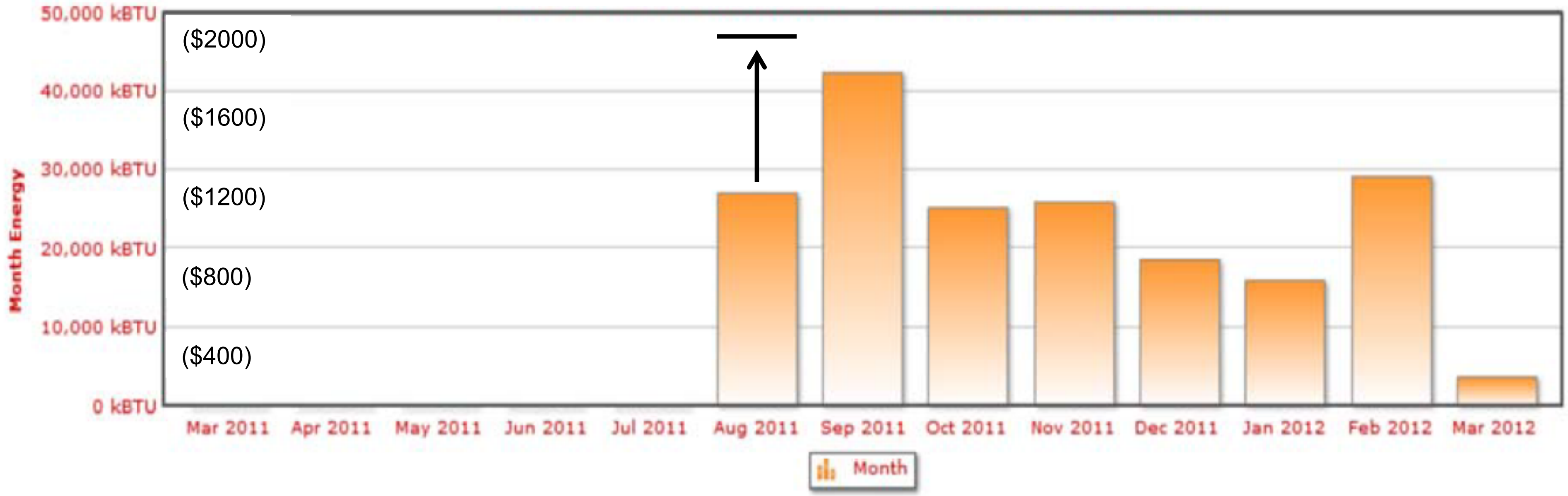
Case Study- NH Correctional Facility

Energy flow diagram



Annual Energy Data



- System Commissioned mid August
- October was a rainy/snowy month
- February was a warmer and sunnier month

Any Questions?

Contact: ross@te2engineering.com